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aSB763.C2F45

United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

CASPR (Computer Assisted Spray Productivity Routine)

User Manual

FPM 95-6
January 1995

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

FPM 95-6
January 1995

CASPR (Computer Assisted Spray Productivity Routine)

User Manual

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CASPR
(Computer Assisted Spray Productivity Routine)

USER MANUAL

CASPR was written to complement the USDA Forest Service Equipment Development Center publication entitled *A Method for Comparing Cost & Productivity of Aerial Spray Delivery* by Robert Banaugh, Report 8434-2807, November 1984 (See Appendix D). It explains the calculation methods used in CASPR, and provides a few calculation examples.

SYSTEM REQUIREMENTS: IBM PC/XT/AT compatible with 512K of RAM, a Microsoft compatible mouse is supported, but optional.

DISTRIBUTION DISK CONTENTS:

CASPR.EXE	The CASPR executable code
CASPR. HLP	On-line help module for CASPR
EX1.DAT	File containing data used in Example 1 in Banaugh
EX2.DAT	File containing data for Example 2
EX3.DAT	File containing data for Example 3

INSTALLATION: Create a subdirectory called CASPR and copy all files from the diskette to this subdirectory.

STARTING CASPR: Go to the subdirectory CASPR and at the system prompt type the following command.

```
CASPR
```

Press ENTER/CR. If your system has a monochrome display attached to a color card, or if you would prefer not to use color, start the program with the following command:

```
CASPR /M
```

The switch (/M) instructs CASPR to reset the screen colors to monochrome.

USING MENUS: There are two menus that appear in CASPR: A Main Menu and an Enter Data Menu. They are used to select functions in the program. These menus can be used with either a mouse or the keyboard. To use the mouse, just move the mouse cursor over the menu choice you want and click the left button. To use the keyboard, press the up or down arrow keys to move the highlight bar to the desired

menu item. Pressing the ENTER/CR key will select it. You may also type the first character of the menu item to highlight it, and press ENTER/CR to select it.

USING WORKSHEETS: Worksheets are CASPR's principle means of entering, editing, and viewing data. They consist of headings or labels that tell you what the values represent, and fields that contain the actual numbers. When you first enter CASPR, the worksheets contain only default values (mostly zero's). When data files are read (via a selection from the Main Menu), the fields in the worksheets are filled with the data from the file. The data in the fields may be changed at any time by placing the worksheet cursor in the field and typing in new values. The worksheet cursor can be moved using the mouse or the keyboard. To use the mouse, place the mouse cursor in the field you want to edit and click the button. The worksheet cursor will jump to that position in the field. You may then move the mouse cursor out of the way and begin editing the field. To use the keyboard to position the worksheet cursor, these keys may be used: The UP/DOWN ARROWS will move up and down in a column, and the ENTER/CR key moves horizontally to the next field. The LEFT/RIGHT/HOME/END keys move the cursor within the field. The CTRL-END key sequence toggles between overwriting existing characters and inserting new characters. Additionally, two of the worksheets can edit more rows of values than can be displayed at once. For these worksheets, the CTRL-PGUP and CTRL-PGDN keys scroll the display ten lines forward or backward.

GETTING HELP: If at anytime in CASPR you need it, help is available. From the menus, choose the HELP section (see USING MENUS). From anywhere else in the program, just press the F1 key. Sometimes several levels of help will be available. Pressing the F1 key again will produce more and more specific help. Pressing the F2 key will back out of help. When in help, the mouse may be used to go up or down the levels by placing the mouse cursor in one of the boxes in the lower right corner of the help window and clicking the button.

A SAMPLE SESSION: The following is one possible sequence of events for entering new data into CASPR. From the Main Menu, choose Enter Data. The Enter Data Menu will appear. From this menu, choose General Data Worksheet. The General Data Worksheet will appear. Enter data into all of the fields as described above. Press ESC or F2 to leave the worksheet and return to the Enter Data Menu. Choose Spray Area Worksheet from the menu and the Length/Width Worksheet will appear (if you had changed the spray area shape to IRREGULAR, a different worksheet would appear). Enter the length and width of the field. Press ESC or F2 to leave the worksheet and return to the Enter Data Menu. Choose Ferry Data Worksheet from the menu and the Ferry Data Worksheet will appear. Enter appropriate data, then press ESC or F2. Now select Calculate Results from the Enter Data Menu. The Calculation Summary windows will appear. These windows look like worksheets, except that none of the numbers can be changed. If you would like to print any of

[illegible]

[illegible] WORKSHEETS: Worksheets are [illegible] ng, and viewing data. They consist of headings [illegible] any item, and fields that contain [illegible] contents [illegible] with a selection from the Main Menu [illegible] the data from the file. The data in the [illegible] the worksheet [illegible] be moved using the [illegible] will jump to that position [illegible] out of the way and begin editing the field [illegible] worksheet cursor [illegible] up and down in a column and [illegible] CTRL-END key sequence [illegible] writing new characters. Additional [illegible]

GETTING HELP: [illegible] menu, place the [illegible] just press the F1 key. Sometimes [illegible] help [illegible] the F1 key again will [illegible] help [illegible] move out of help. When [illegible] help [illegible]

[illegible]

these pages, press SHIFT-PRTSC.

SAVING and READING FILES: The three example files included on the distribution diskette (EX1.DAT, EX2.DAT, and EX3.DAT) contain the input data from the three examples in the Banaugh document (Appendix D). They may be used to illustrate the file handling functions of CASPR. From the Main Menu of CASPR, select Read Data From File. When the window opens, enter EX1.DAT (preceded by the drive letter and path, if necessary) and press ENTER/CR.

When the window closes, the data has been read. Now select Review Calculations from the Main Menu. The calculation sheets should contain values similar to those in Banaugh. Now make a change in the data. Go to the General Data Worksheet (from the Input Data Menu) and change the application rate. Leave the worksheet and select Calculate Results from the menu. Note the changes in the results. Now save this new data in a new file. Go back to the Main Menu and select Write Data To File. When the window opens, type NEW1.DAT (preceded by drive letter and path, if necessary) and press ENTER/CR. A new data file will be written.

Questions or comments about CASPR should be directed to:

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P.O. Box 3073
Princeton, NJ 08543
(609)734-9282

SAVING and READING [illegible] files include [illegible]. [illegible] (EXLDAT, [illegible] and [illegible]) [illegible] input data [illegible] three [illegible] in the [illegible] (Appendix [illegible]). [illegible] [illegible] of CASPR. From the Main Menu of CASPR, select Read [illegible] the [illegible] window [illegible] EXLDAT (provided by the [illegible] [illegible] and press [illegible].

[illegible] closes, the data has been read. Now select Review [illegible] Main Menu. The [illegible] [illegible] Now make a change in [illegible]. Go to the General Data [illegible] Data Menu) and change the application [illegible] Calculate Results from [illegible] data [illegible]. [illegible] the Main Menu and select Write Data [illegible]. [illegible] NEWDAT [illegible] (if necessary) and press [illegible]. A new data file will be written.

Questions or comments about CASPR should be directed to:

APPENDIX A

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ENGINEERING
IN AGRICULTURE

SELECTED CONTRIBUTIONS IN
ENGINEERING FOR AGRICULTURE AND OTHER
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VALIDATION OF THE CASPR AERIAL SPRAY EFFICIENCY MODEL

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Reprinted from
March 1993 Vol. 9 No. 2 199-203

American Society of Agricultural Engineers
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Validation of the CASPR Aerial Spray Efficiency Model

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Abstract. *This article describes the implementation of the Baltin-Amsden formula, a method for estimating the cost of an aerial spray operation, onto personal computers through the CASPR (Computer Assisted Spray Productivity Routine) program. The CASPR predictions are compared to observed data taken during the 1991 Gypsy Moth Eradication Program run by the Utah Department of Agriculture, Division of Plant Industry. The model is able to predict the total times of the aerial spray operation to within 23%, on average, and therefore, provides a means of estimating quickly the cost of any aerial spray operation scenario.* ***Keywords.** Aircraft, Aerial spray, Cost, Computers, Forestry.*

A principal tool for the management of forest insect infestations is the application of pesticides by aircraft. Since treatment areas are frequently remote, large, and inaccessible by ground transportation, a successful aerial spray application requires careful preparation and planning, as well as comparing different spray application strategies. Two quantitative measures of effectiveness of such strategies are spray productivity and efficiency. Spray productivity is represented by the ratio of the area sprayed to the total aerial spray operation time. Spray efficiency is represented by the ratio of the time spent actually applying the spray on the target area to the total aerial spray operation time.

These measures of effectiveness were first quantified in the Baltin-Amsden formula (Amsden, 1960). In contrast to previous cost estimation methods, this formula emphasizes that the cost for aerial spraying should be based on field or spray path length rather than solely on the size of the area to be sprayed. Banaugh (1984), under contract to the USDA-Forest Service, Missoula Equipment Development Center, modified the formula to account for irregularly shaped and topographically varied spray areas, and presented a systematic and orderly calculation procedure for predicting spray productivity and efficiency. This procedure has been implemented into the personal computer program CASPR by Curbishley (1988), and reported by Ekblad et al. (1988). This article summarizes the use and validation of this model with actual field data.

Program Description

The CASPR requires a DOS-compatible personal computer with at least 512KB of memory. Written in Microsoft QuickBASIC 4.5, CASPR is designed to be "user friendly". It makes use of two main menus that permit the user to easily select functions and options available in the program. The CASPR contains an extensive HELP menu whose use enables the user to become operationally familiar with the program in a relatively short period of time. Results are displayed graphically and clearly labeled. The program, along with some typical examples, is available on a single floppy disk (Continuum Dynamics, Inc., P. O. Box 3073, Princeton, NJ 08543) at no cost.

In order to predict time and cost elements of an aerial spray operation, CASPR requires as input specific data including application rate, tank capacity, flying speeds, hourly costs, turning times, and the number and lengths of spray paths flown. In this way, the time for a spray operation may be interpreted as the sum of several distinct operations: loading time + spray time + turning time + ferrying time + travel time between blocks. These data are fed into the Baltin-Amsden formula (Amsden, 1960) in this same order:

$$t = 10^4 \left(\frac{T_r Q}{Q_f} + \frac{1}{v\,b} + \frac{T_w}{b\,L} + \frac{2\,a\,Q}{V\,Q_f} + \frac{C}{V\,F} \right) \quad (1)$$

where

- t = total aerial spray operation time (s/ha)
- T_r = loading time (s)
- Q = application rate (L/m^2)
- Q_f = spray material applied per spray cycle (L)
- v = spraying speed (m/s)
- b = swath width (m)
- T_w = turning time (s)
- L = spray length (m)
- a = ferrying distance (m)
- V = ferrying speed (m/s)
- C = distance between spray blocks (m)
- F = spray block area (m^2)

At program operation, the above items and values listed below must be available, known, or estimated:

1. A topographical map showing the target area and the surrounding area.

Article was submitted for publication in September 1992; reviewed and approved for publication by the Power and Machinery Div. of ASAE in February 1993.

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2. A drawing to a scale sufficient to permit the simultaneous location of helispots and/or airfields and the target area.
3. The pesticide application rate (Q), the pesticide tank capacity (Q_f), and the spraying speed of the aircraft (v).
4. The loading time per spray cycle (T_r).
5. The hourly costs of loading the pesticide, spraying, ferrying, and turning.

Given these data, entered by the user into screen menus, CASPR quickly predicts total times and costs of the aerial spray operation. A flowchart of CASPR program operation is shown in figure 1. Calculations of spray productivity and efficiency are based upon the following assumptions:

1. The amount of pesticide carried each spray cycle is the same.
2. The spray swath width is the same for each spray cycle.
3. The operations accounted for in the cost estimate are (a) loading and fueling the aircraft, (b) ferrying the aircraft to and from the loading strip and between swaths, (c) spraying and touching up, and (d) turning.
4. The aircraft is loaded and fueled at a local helispot or airstrip (loading time is defined as the time from "wheels down" to "wheels off").
5. The total touch-up time is directly proportional to the sum of the spraying and turning times.
6. The decision to terminate a spray cycle is due solely to the exhaustion of the pesticide contained in the spray tank and is independent of the fuel supply and the fuel consumption rate of the aircraft.
7. The time required to spray the last load is the same time as the time required to spray a full load; no allowance is made for the fact that the final load of the spray operation may only be partially used.

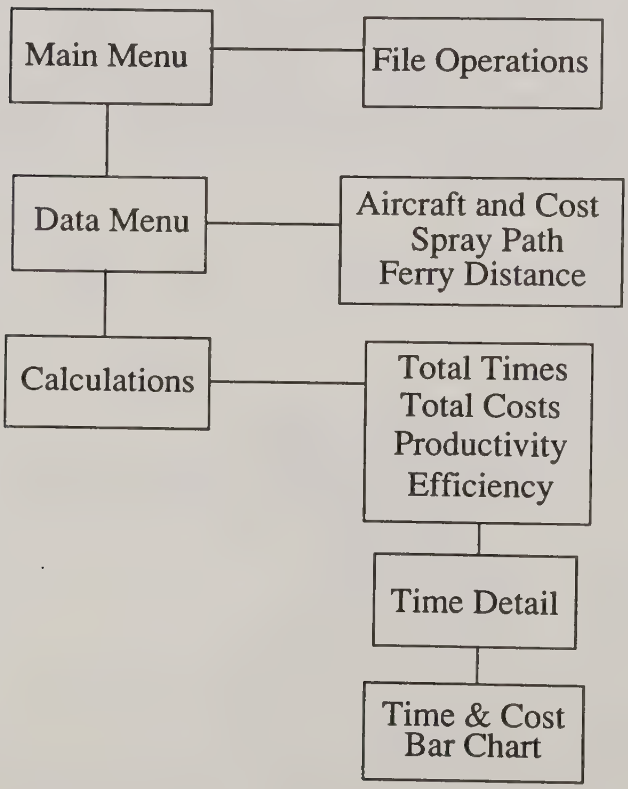

Figure 1–Flowchart of CASPR program operation showing access to input data and order of display of calculated values.

Method

The validation data was gathered by observing spray operations conducted during the 1991 Gypsy Moth Eradication Program by the Utah Department of Agriculture, Division of Plant Industry (Munsen and Anhold, 1991). This eradication program targeted 12 110 ha (30,000 acre) for treatment encompassing portions of Davis, Salt Lake, Summit, Utah, and Wasach Counties, Utah. Its purpose was to eradicate gypsy moths in their present locations in these counties and prevent further spread within the state.

A few simple observation and recording methods provided the data needed to run CASPR and additional data needed for comparison and verification of the model predictions (Curbishley, 1992). The steps in acquiring the data and accessing the model were the following:

Gathering Pre-mission Data

Two types of helicopters were flown during the spray mission: two Bell 206B III and one Hughes 500D. Before the spraying operations began, the pilots of these aircraft provided information about operational costs (ferrying, turning, spraying, touching up, and loading), operational speeds (ferrying, turning, spraying, and touching up), the expected volume of spray material per spray cycle, the application rate, and the expected swath width.

Observing Spraying and Turning Operations

All necessary flight data were gathered by observing the clock times at which the spray was turned on for a spray pass, turned on for a touchup pass, turned off for a normal turn, or turned off for ferrying or reloading. The total times for spraying, turning, ferrying, and loading could be determined by calculating the differences in on/off clock times and adding them together.

Observers were placed at strategic ground locations and, whenever possible, in a chase aircraft. Both locations for observers led to occasionally missing important data time increments. Ground observation was sometimes difficult because spray length was as great as 3 km and because the terrain sometimes blocked the view. Aerial observers, on the other hand, could miss a spray event because the chase aircraft was turning or was too far from the spray aircraft. Overall, an estimated 15% of the data was missed.

Observing Ferrying and Loading Operations

The standard procedure for load checkers was to record the times of aircraft "wheels down" and "wheels off", usually to the nearest minute. Unfortunately, this approximation was not precise enough for later calculations.

Determining the Spray Region Area and Spray Path Length

The spray area and the lengths of the spray paths are two critical pieces of information to CASPR, and are generally the most difficult pieces of data to obtain accurately. Because many of the spray blocks in this particular project were large [spray block size ranged from

27 to 366 ha (67 to 900 acre)], often only portions of a block would be treated on one day, with perhaps two aircraft treating different portions of the block simultaneously. Every day a map would be marked with the approximate boundaries of the areas treated, along with notes as to the flight paths taken by the aircraft. Later, this geometry was digitized into the computer to calculate the approximate spray areas. Standard 1:24,000 scale topological maps were placed on a digitizing tablet with an approximate resolution of 300 divisions per inch. For this configuration, one division on the digitizing tablet corresponds to 2 m (6.6 ft) in the real world.

Two aspects of this method introduce inaccuracies into the calculation. First, although the spray block corner points were known, the portions treated on one day were not very accurately known [only to within a swath width, or about 30 m (100 ft)]. Second, the terrain treated was often very complex. Hills and canyons cause the actual treated area sizes to differ from those projected onto a flat map [elevation varied as much as 75 m (250 ft)]. For this reason flight paths were rarely straight, since the aircraft would generally follow the terrain contours vertically and horizontally. The correction technique suggested by Banaugh (1984) for complex terrain requires the determination of the actual spray path lengths from topographical maps. This task proved to be difficult in practice. However, when approximating flight paths, an effort was made to conform to the gross horizontal features of the terrain, even though the actual flight paths were more complex and therefore of different lengths.

Entering Data into the Model

Two data sets were created to contain basic information about each aircraft. From these data sets, new data sets containing area and flight path length information were created for each spray area. When more than one area in the spray block was treated by the same aircraft, all the smaller areas were added together and treated as one larger area. When more than one aircraft was used to treat one or more regions in the same spray area, each aircraft was considered to be on an individual mission.

Determining Data for Comparison with Model Predictions

Spraying time for each mission could be calculated by adding together the individual spray times for all of the passes. Turning time and touchup time can similarly be computed. The target material flow rate is known from the pre-mission data, and the loading time can be determined from the load checker data sheets. Thus, the quantities that can be compared are spraying time, turning time, touchup time, total flying time, loading time, total operation time, number of spray cycles, and flow rate.

Table 1 summarizes some of the inputs into the model. Variables are defined after equation 1. All values were obtained from the pilots of the aircraft.

Table 1. Pre-mission aircraft data showing costs, speeds, and target values for application rate and swath width*

Variable	Notation	Bell 206B III	Hughes 500D
Ferrying Cost ($ / h)		250	240
Turning Cost ($ / h)		250	475
Spraying Cost ($ / h)		250	475
Touchup Cost ($ / h)		250	475
Loading / Fueling Cost ($ / h)		0	50
Avg. Loading Time (min)	Tr	2	2
Load Size (L)		265	265
Ferrying Speed (m / s)	V	35.8	44.7
Turning Speed (m / s)		15.7	8.9
Spraying Speed (m / s)	v	31.3	33.5
Touchup Speed (m / s)		31.3	33.5
Application Rate (L / ha)	Q	4.7	4.7
Application Rate (L / min)		28.4	28.4
Swath Width (m)	b	30.5	27.4

* These values were supplied by the pilots, and may not necessarily be consistent. For example, the loading cost for the Bell 206B III was bundled with other costs and is reflected in CASPR as 0. Also, the conversion of application rate with swath width is inconsistent with accepted formulas.

Discussion

Table 2 shows percent differences between CASPR predictions and observed data for the 13 spray operations considered. The original Banaugh (1984) formulation, when applied, tended on this data set to consistently overpredict the total operation time computed by equation 1. Specific empirical correction factors were introduced to attempt to correct the spray time, turning time, and touchup time. The values of these correction factors were obtained by a least squares analysis technique. The original values of 1.0 (by default) were corrected to 0.82, 0.54, and 1.29, respectively. The overall average difference between prediction of total operation time and the data was, with this procedure, reduced to less than one percent, with the RMS value for all data comparisons at 23%.

While the average difference between the predictions and the data are good, there remains a great deal of variability from area to area, as indicated by the large RMS difference. Much of this disagreement may be attributed to the inaccuracies involved with estimating areas and path lengths, variations in aircraft speed, mid-mission reconnaissance passes, and timing variations brought about by the observational difficulties discussed previously. One spray area, "Mueller D", was not considered here because the recorded data did not correspond to the flight paths indicated on the map after the mission. Average times for a spray project can be computed by CASPR and displayed graphically, as shown in figure 2.

Table 2. Differences between CASPR predictions and observed data in percent*

Treatment Block Areas	Spraying Time	Turning Time	Touch-up Time	Total Flying Time	Loading Time	Total Operation Time	Flow Rate
Mt. Dell A	10	5	–25	4	–25	–1	–9
Mt. Dell B	11	11	n / a	11	–45	–2	–9
Knudsen	3	6	–61	–8	0	–6	–7
Burr Fork	–16	4	n / a	–7	–50	–6	–9
Bear Hollow	–14	10	n / a	–4	–33	–10	–7
Miller A	41	15	n / a	38	100	48	–9
Miller B	–31	48	n / a	–6	0	–5	–7
Mueller A	–20	22	n / a	–11	0	–9	–9
Mueller B	47	46	n / a	47	100	59	–7
Mueller C	–19	19	n / a	–11	–33	–18	–9
Red Butte	–15	–1	n / a	–11	–62	–25	–9
Deaf Smith	–36	0	n / a	–23	100	–11	–9
Big Bear	0	0	n / a	0	0	0	–9
Average	–3	13		–6	4	1	–8
RMS	25	21		19	56	23	9

* Positive numbers indicate CASPR overpredicted the value, while negative numbers indicate CASPR underpredicted the value.

Because the applicators arranged a single contract fee for all of the spraying, only the average price per hectare (from the contract) could be compared with CASPR predictions, as shown near the bottom of table 3. The CASPR does not include calculations for spray mission down time (when it rains, for instance) or contractor profits. These factors could potentially increase the projected contractor costs significantly, but, when included, still leave room for additional profit in a spray job. Pre-mission computations with CASPR may have helped to quantify details about contractor costs on this project.

Also of note in table 3 are the values for spray productivity and efficiency. Spray productivity, the average area treated per hour, varied greatly according to the estimated area, the number of spray passes, and the average length of a turn. Spray efficiency, representing spraying time divided by total operation time, averaged 51%.

Table 3. Some additional predicted values from CASPR

Treatment Block Areas	Aircraft	Total Operation Cost ($)	Cost per Unit Area ($ / ha)	Cost per Unit Time ($ / h)	Productivity (ha / h)	Efficiency (%)
Mt. Dell A	Hughes	348.82	2.10	423.41	200.91	57
Mt. Dell B	Hughes	319.43	2.89	419.22	144.46	51
Knudsen	Bell	43.76	1.36	250.00	184.03	45
Burr Fork	Hughes	84.89	3.16	407.07	128.86	42
Bear Hollow	Bell	48.72	1.80	213.49	117.75	44
Miller A	Bell	124.79	1.33	383.29	285.88	62
Miller B	Hughes	30.79	1.01	196.75	196.52	40
Mueller A	Hughes	67.72	1.21	392.82	326.31	53
Mueller B	Bell	43.27	0.94	180.48	194.12	58
Mueller C	Hughes	47.46	1.78	365.81	205.87	49
Red Butte	Hughes	404.63	1.11	416.65	377.13	57
Deaf Smith	Hughes	122.35	1.01	385.68	381.44	58
Big Bear	Hughes	144.57	1.78	397.16	223.46	49
Average			1.66	340.91	228.21	51
Contracted Costs			9.22	437	47.40	

Sources of Error

Differences between values predicted by CASPR and observed in the field came from errors in the observed data and from simplifications used in the model itself. Data for this study were obtained from three sources: (1) the helicopter pilots provided cost, speed, application rate, and swath width information about their aircraft; (2) spraying, turning, and ferrying times were recorded by ground-based or aerial observers using synchronized clocks; and (3) spray areas and spray path lengths were estimated using topographical maps.

Errors can be associated with all three of these data collection methods. Values for spraying speed, application rate, and swath width are all target values; during the spray operation, some variation can be expected in them. Observers noting spray on and spray off times must decide visually when these events occur. Often this task is made more difficult by distance, lighting, or an obstructed view.

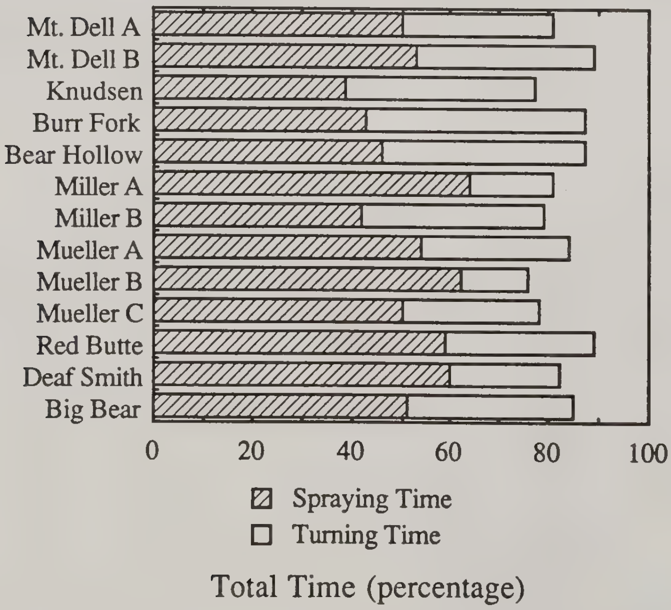

Figure 2–Display of total times as computed by CASPR, combining the observed spraying times with turning times for the 13 spray blocks.

Finally, estimating true spray path lengths and areas using topographical maps is an approximate process. Overall, errors in recording data and interpolating topographical maps may be as high as 30%.

The spray areas for each mission were indicated by hand drawing the estimated boundary locations on 1:24,000 scale topographical maps. While the corners of the spray blocks could be accurately placed on these maps, clearly the smaller spray areas could only be approximated. At the scale of these maps, the width of the marking pen line itself represented approximately 30 m (100 ft), similar to one swath width. Small deviations in the markings of the spray regions translate into large errors in area and spray path length estimates. Since these two quantities are essential to the predictions, these approximations probably account for most of the differences with the data.

These results build on the assumptions found in Banaugh (1984) for fixed-wing aircraft, and suggest that a future field test of the model should be made, with better observational data, ideally for a helicopter and a fixed-wing aircraft.

Conclusions

The CASPR is a versatile computer tool for analyzing the spray productivity and efficiency of the design of a particular aerial spray operation. With this program, the effect of altering a specific plan may be quickly determined, thereby permitting the optimization of the spray operation. The CASPR predicted the values for total operation time to within 23% RMS (errors ranged from –25% to 59% in individual cases). Inaccuracies in the data collected are probably also within this same percentage difference.

Increasing the number of ground observers and/or using aerial observers would help to increase accuracy in the observed data. Future data collection should insist on more precise load checker times (more accurate than 1-min intervals). And, further studies should be conducted to compare predictions for fixed-wing aircraft and other types of terrain where large-scale control operations are or likely will be considered. With sufficiently accurate on-board instrumentation, the spray aircraft position, spray on and

spray off times, etc., could all be recorded by computer for recovery after the treatment.

This study has shown that it is essential to estimate accurately the area and spray path lengths flown when computing spray operation costs. Table 3 suggests that even with the 23% RMS error present in CASPR, the spray operation was a financial success for the contractor. The CASPR accuracy (as demonstrated in these field studies) would suggest that the model is ready for use by contractors and operators alike, to enable them to gauge the relative costs of spray mission components and estimate profitability of specific spray operations.

Acknowledgments. The authors wish to extend their appreciation to those individuals connected with the 1991 Gypsy Moth Eradication Program in Salt Lake City, Utah, for their cooperation with this valid`tion study. Without their assistance, this data collection and validation would not have been possible: John Anhold, Steve Munsen, Mark Quilter, and Patricia Skyler. The first two authors also acknowledge the sponsorship of the USDA-Forest Service for supporting this research and article preparation.

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APPENDIX B

United States Department of Agriculture

Forest Service

Forest Pest Management

Davis, CA

1991 CASPR Spray Aircraft Efficiency Model - Validation Study

FPM 92-8
July 1992

FPM 92-8
C.D.I. Technical Note No. 91-10
July 1992

1991 CASPR Spray Aircraft Efficiency Model - Validation Study

by

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Summary

Predictions of the computer code CASPR (Computer Assisted Spray Productivity Routine) were compared to observed data taken during the 1991 Gypsy Moth Eradication Program run by the Utah Department of Agriculture, Division of Plant Industry. After some tuning, the CASPR model was able to predict the total times of the aerial spray operations to within 20 percent. Improvements with the predictive model will come with additional, carefully monitored field data.

The author wishes to extend his appreciation to those individuals connected with the 1991 Gypsy Moth Eradication Program in Salt Lake City, Utah for their cooperation with this validation study. Without their assistance, this data collection and validation would not have been possible: John Anhold, Steve Munsen, Mark Quilter and Patricia Skyler.

Introduction

Predicting the cost and time required for an aerial spray application is a concern to anyone planning such an operation. The computer code CASPR (Computer Assisted Spray Productivity Routine, Ref. 1 and 2) has been developed by the USDA Forest Service to help plan such missions. The 1991 Gypsy Moth Eradication Program conducted by the Utah Department of Agriculture, Division of Plant Industry and the USDA Forest Service (Ref. 3), provided an opportunity to exercise the CASPR model in a real-world situation. This report describes the methods used to gather and analyze data, and the analysis and findings.

Objective

The objective of this study is described in three parts:

1) Exercise the CASPR computer code under real-world conditions and compare its predictions to observed values.

2) Understand conditions under which the model can and cannot be expected to perform well.

3) Suggest possible enhancements to the model that would improve its predictive ability.

Scope

The data for this validation study was gathered by observing spray operations conducted during the 1991 Gypsy Moth Eradication Program by the Utah Department of Agriculture, Division of Plant Industry (Ref. 3). This program targeted for treatment 29,925 acres that encompass portions of Davis, Salt Lake, Summit, Utah, and Wasach counties, Utah. Its purpose was to eradicate gypsy moths in their present location in these counties and prevent further spread within the state.

Code Operation

"The Baltin-Amsden Formula" (Ref. 4) describes a method for estimating the cost of an aerial spray operation. Banaugh (Ref. 5), under USDA Forest Service contract, modified the Baltin-Amsden formula to account for irregularly shaped and topologically varied spray areas. The CASPR code implements Banaugh's procedure on a personal computer. In order to predict time and cost elements of a spray operation, CASPR requires as input specific data including application rate, tank capacity, flying speeds, hourly costs, turning times, and the number and lengths of spray paths to be flown. Given these data, CASPR quickly predicts total times and costs of the spray operation.

Methods

A few simple observation and recording methods provided the data needed to run the CASPR model and additional data for comparison. When more than one observer noted event times for a particular run, their time pieces were synchronized to a standard reference.

Gathering Pre-mission Data

Two types of aircraft were flown during the spray mission: two Bell 206B III and one Hughes 500D helicopters. Before the spraying operations began, the pilots of these aircraft provided information about operational costs (ferrying, turning, spraying, touching up, and loading), operational speeds (ferrying, turning, spraying, and touching up), the expected volume of spray material per load, the application rate, and the expected swath width. A sample form is shown in Figure 1, and the data are shown in Table 3 in the Appendix, along with an application example, shown in Figures 3 to 8, and Table 4.

Observing Spraying and Turning Operations

All of the flight data needed to run the model was gathered by observing and noting the clock times when the aircraft turns the spray on and off, and what the aircraft is doing when the spray is on or off. By calculating the differences in on/off times and adding them together, the total times for spraying, turning, ferrying, and loading can be determined. Observers were given data sheets on which they were to note observations of the spray aircraft and record the times at which the spray was turned on for a spray pass, the spray was turned on for a touchup pass, the spray was turned off for a normal turn, or the spray was turned off for ferrying or reloading (a copy of this data sheet is in the Appendix in Figure 2). By coordinating these data with the load checkers' data sheets, ferry times and loading times could be obtained.

Observers themselves were placed at strategic ground locations or, when possible, in an observation aircraft. Placing ground observers was difficult and often they could not see all of the spray operations because of extreme distance or because the terrain blocked their view. Even aerial observers occasionally missed a spray event because the chase aircraft was turning or was too distant from the spray aircraft. In the future, using additional aerial observers recording redundant data would help reduce the number of missed events. Depending on the terrain, ground-based observers may not be able to collect sufficiently accurate data.

Observing Ferrying and Loading Operations

The standard procedure for load checkers is to record the times of aircraft landing and liftoff. The load checkers' regular data sheets were used to provide these times. The usual procedure for the load checkers is to record times to the nearest minute. These data sheets were very useful in providing loading times for later comparison, but because the ferrying calculations require times to the nearest second, ferrying times were not compared. Loading times were compared, but since the resolution of one minute is large compared to the typical loading time of a few minutes, large differences were common. Future data collection should insist on more precise load checker times.

Determining the Spray Region Area and Spray Path Length

The area of the spray region and the lengths of the spray paths are two critical pieces of information to CASPR. Unfortunately, these quantities also proved to be the most difficult pieces of data to obtain accurately.

Because many of the spray blocks in this project were so large, often only portions of a block would be treated on any given day. Sometimes two aircraft would treat different portions of the block simultaneously. (In these instances, the two aircraft are viewed as flying separate missions.) After a day's spraying, a map would be marked with the approximate boundaries of the regions treated, along with notes as to the flight paths taken by the aircraft. Later, this geometry was digitized into a computer. The computer was used to calculate the approximate areas of the spray regions and the approximate lengths of the spray paths.

Two aspects of this method introduce inaccuracies into the calculations. The first is that, while the spray block boundaries can be marked very accurately, the smaller spray regions treated on any particular day cannot be marked as accurately. When digitizing the maps, variations in the boundary locations cause variations in the computed area. Second, the terrain treated was often very complex. Hills and canyons cause the actual treated area sizes to differ from those projected onto a flat map. For this same reason flight paths were rarely straight. The pilots would follow the terrain as it curved around corners and rose and dipped in the hills. When approximating flight paths, an effort was made to conform to the gross features of the terrain, but the actual flight paths were more complex and therefore of different lengths.

Entering Data into the CASPR Model

Two "base case" CASPR data sets were created that contained the basic information about each aircraft. From these basic data sets, new data sets were created for each spray region that contained area and flight path length information. When more than one region in the spray block was treated by the same aircraft, all the smaller regions were added together and treated as one larger area. When more than one aircraft was used to treat one or more regions in the same spray block, each aircraft was considered to be on an individual mission.

CASPR models spray areas in two ways. The first, as a rectangular area, was not used in this comparison because none of the spray areas was truly rectangular. The second way, as an "irregularly" shaped area, was used exclusively because it allows the entry of individual flight path lengths.

Determining Data for Comparison with CASPR

Spraying time for each mission could be calculated by adding together the individual spray times for all of the passes. Turning time and touchup time can similarly be computed. The touchup constant used in CASPR is computed by dividing the total touchup spraying and touchup turning time by the total spraying and turning time. The present default value of 0.1 was used in this study. The target material flow rate is known from the pre-mission data, and the loading time can be determined from the load checker data sheets. Thus, the quantities that can be compared are spraying time, turning time, touchup time, total flying time, loading time, total operation time, number of spray cycles, and flow rate.

Data Analysis

Table 1 shows percent differences between CASPR's predictions and the observed data for the 13 spray operations considered. A positive number in this table indicates that CASPR overpredicted the value.

In order to increase CASPR's future accuracy, empirical correction factors were introduced permanently into CASPR's internal equations to adjust the results in the direction of the data. The overall average difference between prediction and data was minimized to below one percent.

While the average difference between the CASPR predictions and the observed data was good, there remained a great deal of variability from case to case. Much of this disagreement can be attributed to the inaccuracies involved with estimating areas and path lengths, as previously discussed. Other sources of error may include variations in aircraft speed, mid-mission reconnaissance passes, and timing variations brought about by the observational difficulties discussed previously. The predictions for one case in particular, "Mueller D", differed so greatly from the data (probably because of invalid assumptions about the flight paths), that it was not considered with the rest of the data. Still, on average CASPR predicted the total operation time to within 22% (after correction).

Spraying Time: The most variation of results occurred for this quantity. The difference between predictions and data ranged from -36% to 47%. CASPR calculates this value using an average speed and the total spray path lengths. Variations in these inputs could account for the wild variations in output. The largest errors occurred for runs using the Bell 206B III.

Turning Time: CASPR generally overpredicted this quantity. The difference ranged from -1% to 67%. The model uses an average turning time and the number of turns made to calculate this value and is very sensitive to variations.

Touchup Time: For only two runs was touchup activity reported. For these two runs CASPR underpredicted the time by -25% and -61%. It is interesting to note that the calculated touchup constants were 0.14 and 0.24 for these runs. These values are higher than CASPR's default value of 0.1, as suggested by Banaugh (Ref. 5).

Total Flying Time: CASPR generally overpredicted this value also. The range of errors was -23% to 47%. This value is heavily dependent on the accuracy of its components: spraying time, turning time, and touchup time.

Loading Time: Loading time is measured in whole minutes and is usually from 1 to 4 minutes in length. Therefore if there is any difference between predicted and observed values, it appears large. CASPR takes its predicted number of spray cycles and multiplies it by an average loading time to get this quantity. Thus, loading time accuracy is dependent on measurements of spray path lengths and predictions of aircraft speed. CASPR accurately predicted this value about 30% of the time. The misses ranged from -62% to 100%.

Total Operation Time: This is the sum of spraying time, turning time, touchup time, and loading time. Total operation time can only be as accurate as its components. The error range here is from -25% to 48%.

Number of Spray Cycles: Like loading time, the number of spray cycles is a small, integer value. If it differs from its predicted value at all, it differs greatly. Still, CASPR correctly predicted this value almost 75% of the time. For the other times CASPR was off by -56% to 100%. CASPR calculates this number based on the total spray path length, the volume of spray material in a single load, its calculation for application rate, and the estimate of aircraft speed.

Flow Rate: It is evident that the flow rate is being predicted consistently. This consistency is due to the fact that CASPR bases its calculation of this value on the application rate, the aircraft speed, and the swath width. All three of these values were constant for the two aircraft types, and compared to a calculated target value. It is not surprising that agreement is good.

Efficiency, Costs and Other Data: Because the applicators arranged a single contract fee for all the spraying done, individual prices for each of the spray operations were not available. Therefore, costs predicted by CASPR (Table 2) could not be compared to actual costs. Even the helicopter pilots indicated that the hourly fee figures provided were "working numbers." Of note in Table 2 are the values for productivity and efficiency. Productivity, the average number of acres treated per hour, varied greatly according to the estimated area, the number of spray passes, and the average length of a turn. Efficiency averaged 55% with a standard deviation of 8%. This value represents spraying time (time spent with the spray boom turned on) divided by total operation time (spraying, flying, and reloading).

Sources of Error

Differences between values predicted by CASPR and observed in the field came from errors in the observed data and from simplifications used in the model itself.

Data for this study were obtained from three sources. The helicopter pilots provided cost, speed, application rate, and swath width information about their aircraft. Spraying, turning, and ferrying times were recorded by ground-based or aerial observers using synchronized clocks. Finally, spray areas and spray path lengths were estimated using topographical maps.

Errors can be associated with all three of these data collection methods in the following ways. Values for spraying speed, application rate, and swath width are all target values. During the spray operation, some variation can be expected. Observers noting spray on and spray off times must decide visually when these events occur. Often this task is made more difficult by distance, lighting, or an obstructed view. Finally, estimating true spray path lengths and areas using topographical maps is a very approximate process.

The spray areas for each mission were indicated by hand drawing the estimated boundary locations on 1:24,000 scale topographic maps. While the corners of the spray blocks could be very accurately placed on these maps, clearly the smaller spray regions could be only approximated. At the scale of these maps, the width of the marking pen line itself represented approximately 100 feet, similar to one swath width. Small deviations in the markings of the spray regions translate to large errors in area and spray path length estimates. Since these two quantities are so essential to CASPR's predictions, these approximations probably account for most of the differences between the data and the predictions.

Conclusions

The purpose of the CASPR program is to provide an estimate of costs and times related to a proposed spray operation. In this study, CASPR predicted the values for total operation time to within 22% standard deviation. The average difference between prediction and data was 0.1%.

The spray time and turning time were corrected to fit these data. Using the least squares minimization technique common in data analysis, the standard deviation of the error never fell below 20%. Inaccuracies in the data collected are probably about this magnitude. Efforts should be made in the future to increase the quality of the observed data. Increasing the number of ground observers and/or using aerial observers would help greatly. Further studies should be conducted to investigate CASPR's predictions for fixed-wing aircraft and for flat terrain.

When using CASPR to make time and cost estimates, this study has shown that it is essential to estimate accurately the area and spray path lengths to be flown. Thus, the use of larger scale maps is recommended. Alternately, some investigation should be undertaken involving only the simplifying assumption of rectangular spray blocks and how they are related to irregular spray blocks.

Recommendations

If future validation studies are conducted, some recommendations for those studies include:

1) Use multiple observers for each spray operation, preferably with one observer located in an observation aircraft.

2) Place an additional observer at the loading sites to record landing and liftoff times to the nearest second so that ferrying times may be compared.

3) Devise a system of landmarks to mark spray area boundaries. The landmarks should be easily located on a map to allow greater accuracy in determining the actual boundaries of the spray areas and the actual spray path lengths. A position-recording device installed on the spray aircraft that could be referenced to a map would be ideal.

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Table 1. Percent differences between CASPR predictions and observed data. Positive numbers indicate CASPR over-predicted the value, while negative numbers indicate under-prediction.

Treatment Block Areas	Spraying Time	Turning Time	Touch-up Time	Total Flying Time	Loading Time	Total Operation Time	Num of Spray Cycles	Flow Rate
Mt. Dell A	10	5	-25	4	-25	-1	0	-9
Mt. Dell B	11	11	n/a	11	-45	-2	0	-9
Knudsen	3	6	-61	-8	0	-6	0	-7
Burr Fork	-16	4	n/a	-7	-50	-6	0	-9
Bear Hollow	-14	10	n/a	-4	-33	-10	0	-7
Miller A	41	15	n/a	38	100	48	100	-9
Miller B	-31	48	n/a	-6	0	-5	0	-7
Mueller A	-20	22	n/a	-11	0	-9	0	-9
Mueller B	47	46	n/a	47	100	59	100	-7
Mueller C	-19	19	n/a	-11	-33	-18	0	-9
Red Butte	-15	-1	n/a	-11	-62	-25	-56	-9
Deaf Smith	-36	647	n/a	-23	100	-11	-33	-9
Big Bear	0	0	n/a	0	0	0	0	-9

Table 2. Some additional predicted values from CASPR.

Treatment Block Areas	Aircraft	Total Operation Cost ($)	Cost per Unit Area ($/ac)	Cost per Unit Time ($/hr)	Productivity (ac/hr)	Efficiency (%)
Mt. Dell A	Hughes	348.82	.85	423.41	496.46	57
Mt. Dell B	Hughes	319.43	1.17	419.22	356.97	51
Knudsen	Bell	43.76	.55	250.00	454.74	45
Burr Fork	Hughes	84.89	1.28	407.07	318.41	42
Bear Hollow	Bell	48.72	.73	213.49	290.95	44
Miller A	Bell	124.79	.54	383.29	706.42	62
Miller B	Hughes	30.79	.41	196.75	485.61	40
Mueller A	Hughes	67.72	.49	392.82	806.32	53
Mueller B	Bell	43.27	.38	180.48	479.68	58
Mueller C	Hughes	47.46	.72	365.81	508.71	49
Red Butte	Hughes	404.63	.45	416.65	931.89	57
Deaf Smith	Hughes	122.35	.41	385.68	942.54	58
Big Bear	Hughes	144.57	.72	397.16	552.18	49

Appendix

This appendix contains the following information:

1) Data sheet used to collect pre-mission data for CASPR (Figure 1).

2) Data sheet used to collect spray events times during actual spraying operations (Figure 2).

3) Summary of pre-mission data for Bell 206B III and Hughes 500D aircraft (Table 3).

4) Map of Knudsen Corner, showing spray boundaries, and spray paths (Figure 3).

5) Observed data for the Knudsen Corner spray operation (Table 4).

6) CASPR program input and output screens for the Knudsen Corner spray operation (Figures 4-8).

Pre-Mission Aircraft Data Sheet

What is the hourly cost of operating the aircraft while

- Ferrying: ____________________
- Turning: ____________________
- Spraying: ____________________
- Touching up: ____________________

What is the hourly cost while fueling and loading the aircraft with spray material:

____

How long does it take to refuel and reload the aircraft with spray material between cycles (the time is from wheels down to wheels up):

____

What is the tank capacity of the spray system: ____________________

At what speed will the aircraft fly while

- Ferrying: ____________________
- Turning: ____________________
- Spraying: ____________________
- Touching up: ____________________

What is the spray application rate: ____________________

What is the swath width: ____________________

Figure 1. Sample pre-mission aircraft data sheet.

CASPR DATA SHEET

NAME: BLOCK: DATE:

PASS	ON TIME	OFF TIME	CONDITION	COMMENTS

ALL TIMES IN HH:MM:SS

→ Ferry
Turn
0 Missed condition
T Touch up

Clock Calibration

Name: Time:
Name: Time:
Name: Time:
Name: Time:

Figure 2. CASPR observation data sheet used for collecting spray on and spray off times and events.

Table 3. Pre-mission aircraft data showing costs, speeds, and target values for application rate and swath width.

	Bell 206B III	Hughes 500D
Ferrying Cost ($/hr)	250	240
Turning Cost ($/hr)	250	475
Spraying Cost ($/hr)	250	475
Touchup Cost ($/hr)	250	475
Loading/Fueling Cost ($/hr)	0	50
Avg. Loading Time (min)	2	2
Load Size (gal)	70	70
Ferrying Speed (mph)	80	100
Turning Speed (mph)	35	20
Spraying Speed (mph)	70	75
Touchup Speed (mph)	70	75
Application Rate (gal/acre)	0.5	0.5
Application Rate (gal/min)	7.5	7.5
Swath Width (feet)	100	90

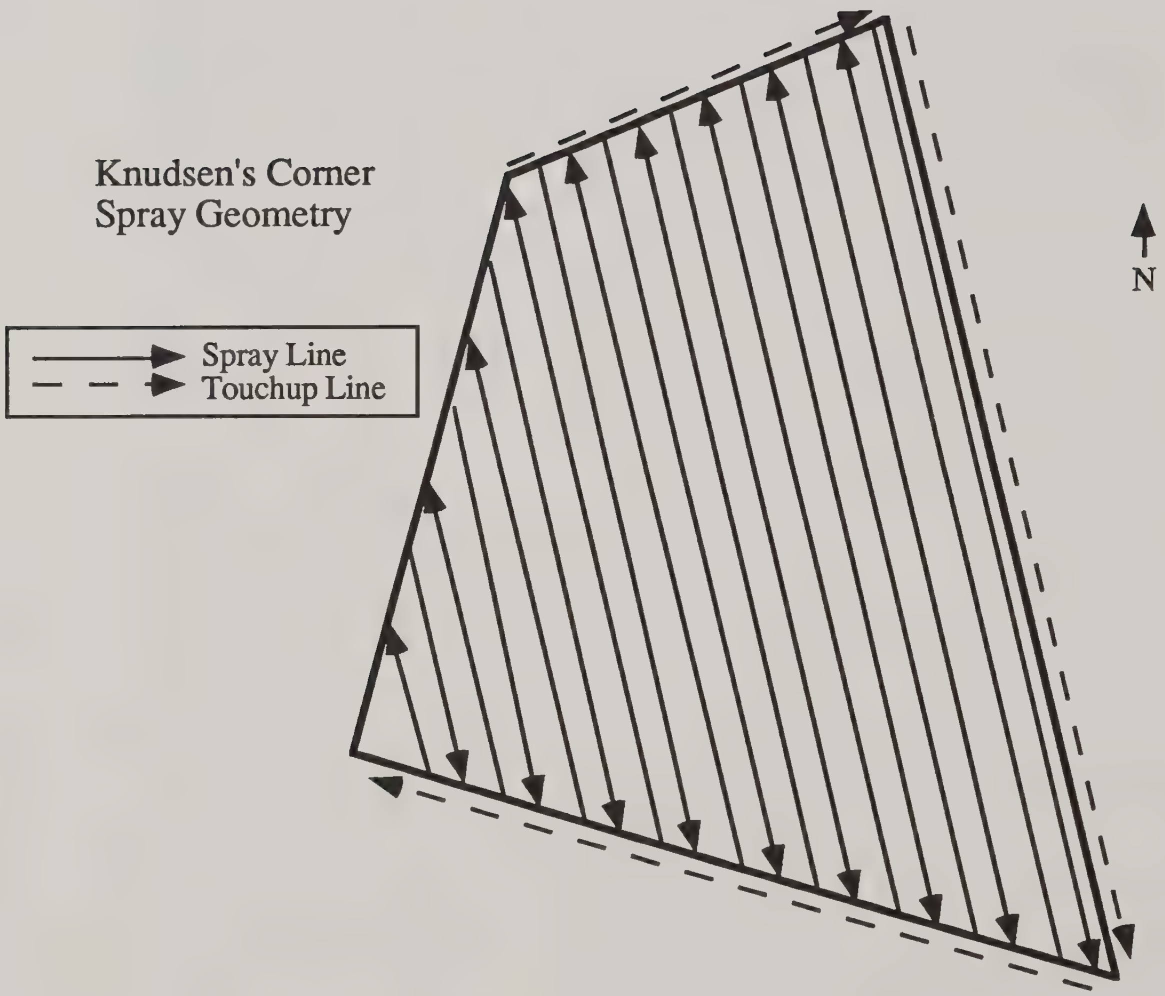

Figure 3. Knudsen Corner spray block geometry showing spray lines and touchup lines (not to scale).

Table 4. Observed data for Knudsen Corner.

Pass	Spraying Time (sec)	Turn Time (sec)	Length (ft)
1	18	17	2746
2	21	18	2693
3	17	15	2587
4	21	16	2534
5	17	17	2429
6	17	20	2376
7	10	13	2323
8	12	16	2218
9	7	11	2165
10	8	14	2059
11	10	23	2006
12	8	14	Touch Up
13	24	20	Touch Up
14	22	20	Touch Up
15	28	17	1637
16	26	15	1162
17	20	-	686

Area = 0.1243 mi^2 = 79.6 acres
Total Spraying Time = 232 min
Total Turning Time = 212 min
Average Turning Time = 17 sec

General Data Worksheet

Application Rate :	.5	gal/acre
Tank Capacity :	70	gallons
Swath Width :	100	feet
Spray Speed :	70	MPH
Ferry Speed :	70	MPH
Turning Time :	16.6	seconds
Aux. Ferry Dis. :	0	miles
Num. Aux. Turns:	0	
Touchup Constant:	.24	
Spraying Cost Rate :	250	$/hour
Ferrying Cost Rate :	250	$/hour
Turning Cost Rate :	250	$/hour
Touchup Cost Rate :	250	$/hour
Loading Cost Rate :	250	$/hour
Loading Time/Cycle :	2	minutes

Press F1 for help, F2 or ESC when finished

Figure 4. CASPR general data worksheet as it appears on the computer screen.

Spray Path Worksheet

Spray Area (ac)= 79.6

Spray Line No.	Spray Line Len. (feet)	Number of Spray Paths Associated With Spray Line	Total Length Of Spray Paths (feet)
1	2746	1	2746
2	2693	1	2693
3	2587	1	2587
4	2534	1	2534
5	2429	1	2429
6	2376	1	2376
7	2323	1	2323
8	2218	1	2218
9	2165	1	2165
10	2059	1	2059
		Tot.= 14	Tot.= 29621
			Tot.= 5.610038 (miles)

Press F1 for help, F2 or ESC when finished, F3 to enter Spray Area

Figure 5. CASPR spray path worksheet as it appears on the computer screen.

```
                     Calculation Summary

Total Operation Cost:               $47.58
Total Operation Time:                11.42 minutes

Cost per unit time:                $250.00 per hour
Cost per unit area:                   $.60 per acre

Productivity:                       418.21 acres per hour
Efficiency:                           50.7%

Total Flying Cost:                  $39.25
Total Loading Cost:                  $8.33

Total Flying Time:                    9.42 minutes
Total Loading Time:                      2 minutes


       Press F1 for help, any other key for next page
```

Figure 6. Calculation summary, screen 1 of CASPR output showing total costs and times.

```
                     Calculation Breakdown

Total Spray Area:                     79.6 acres
Material Flow Rate:                   7.07 gallons per minute

Spray Cycle Distance:                11.55 miles
Number of Spray Cycles:                  1
Total Spray Distance:                 5.61 miles

Number of Spray Turns:                  14
Number of ferry Turns:                   2
Number of Auxiliary Turns:               0
Total Number of Turns:                  16

Spraying Time:                        3.97 minutes
Ferrying Time:                           0 minutes
Turning Time:                         3.63 minutes
Touchup Time:                         1.82 minutes
Total Flying Time:                    9.42 minutes

       Press F1 for help, any other key for next page
```

Figure 7. Calculation breakdown, screen 2 of CASPR output showing time and distance subtotals.

```
                              Time and Cost
              |
Total Time    |__________________________________________________ 100%
Flying Time   |_________________________________________ 82%
Load Time     |_________ 18%
Spray Time    |__________________ 35%
Ferry Time    | 0%
Touchup Time  |________ 16%
Turning Time  |________________ 32%
              |
              |
Total Cost    |__________________________________________________ 100%
Flying Cost   |_________________________________________ 82%
Load Cost     |_________ 18%
Spray Cost    |__________________ 35%
Ferry Cost    | 0%
Touchup Cost  |________ 16%
Turning Cost  |________________ 32%
              |
              +--------------------------------------------------
              0    10   20   30   40   50   60   70   80   90   100
                              Percent of Total

              Press F1 for help, any other key to continue
```

Figure 8. CASPR time and cost graph, showing subtotals relative to total time and cost.

APPENDIX C

PAPER NO. AA88-009

COMPUTER ASSISTED SPRAY PRODUCTIVITY ROUTINE (CASPR)

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JOINT TECHNICAL SESSION

Tropicana Hotel
Las Vegas, Nevada
December 5, 1988

SUMMARY:

The Baltin-Amsden formula was developed to estimate the cost of aerial spray operation. It was later modified to accommodate irregularly shaped and topographically varied spray areas. The paper describes a microcomputer version entitled "CASPR", Computer Assisted Spray Productivity Routine.

KEYWORDS:

Aircraft, Spray, Cost, Computers

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St. Joseph, MI 49085-9659

Computer Assisted Spray Productivity Routine (CASPR)

Abstract

"The Baltin-Amsden Formula" (1959) describes a method for estimating the cost of an aerial spray operation. In contrast to previous cost estimating methods the formula emphasized that the cost for spraying should be based on field or spray path length rather than on the magnitude of the area to be sprayed. Banaugh (1984) modified the Baltin-Amsden formula to account for irregularly shaped and topographically varied spray areas. He also presented two measures of the effectiveness of the delivery of an aerial spray; the **Spray Productivity** and the **Spray Efficiency**. In addition, the work presented a systematic and orderly calculation procedure for predicting the two measures. Recently, Teske (1988) implemented the procedure on a PC microcomputer. The computer-based procedure is entitled, "CASPR" or "Computer Assisted Spray Productivity Routine". This paper to describes CASPR and its use.

A principal tool for managing of forest insect infestations is applying of pesticides by aircraft. Since the target areas are frequently remote, large, and inaccessible by ground transportation, a successful aerial spray application requires much preparation and planning as well as comparing different spray strategies.

Two measures of effectiveness of such strategies are spray productivity and spray efficiency. Spray productivity is the area sprayed per unit time and is the ratio of the spray area to the total aerial spray operation time. Spray efficiency is the ratio of the time spent actually applying the spray on the target area to the total operational flying time. CASPR calculates these measures of effectiveness and permits their graphic display on a terminal and/or a line printer. CASPR also calculates and displays other information of assistance to the aerial spray planner.

Flying Time = Ferrying Time + Spraying Time + Turning Time + Touchup Time

On The Ground Time = Loading Time + Equipment Adjustment Or Repair Time + Aircraft Repair Time

Total Operational Time = **Flying Time** + **On The Ground Time**

Figure 1.–Operational times and their relationbship.

The calculation of productivity and efficiency, as well as the cost of an aerial spray operation, requires an accounting of the completion times of the various phases of the operation (Figure 1).

The calculation of the individual times listed in figure 1 requires a specification of the flight paths. The specification must be made in accordance with the topography and environmental constraints associated with the spray area. Figure 2 is an example of a typical spray path designation.

As figure 2 illustrates, the forest aerial spray paths are usually curved and of different lengths. Therefore, the flying time must be estimated for each path. In contrast, estimating flying times for food crop areas that are typically flat, of uniform height, and rectangular in shape, is considerably simplified because the spray paths are straight and of the same length. Not included in the CASPR calculations are costs of ground transportation to the airfield for aircraft fuel and pesticide, the cost of the pesticide, the costs for purchase or rental of the equipment and its maintenance, as well as the costs for necessary auxiliary supplies, personnel, overhead, spray evaluation, and administration. Such costs were omitted because they vary widely from area to area and depend on conditions peculiar to each spray operation. The omission of these costs implies that the results of CASPR should be used to compare only the direct operational spraying costs for different spraying strategies or tactics.

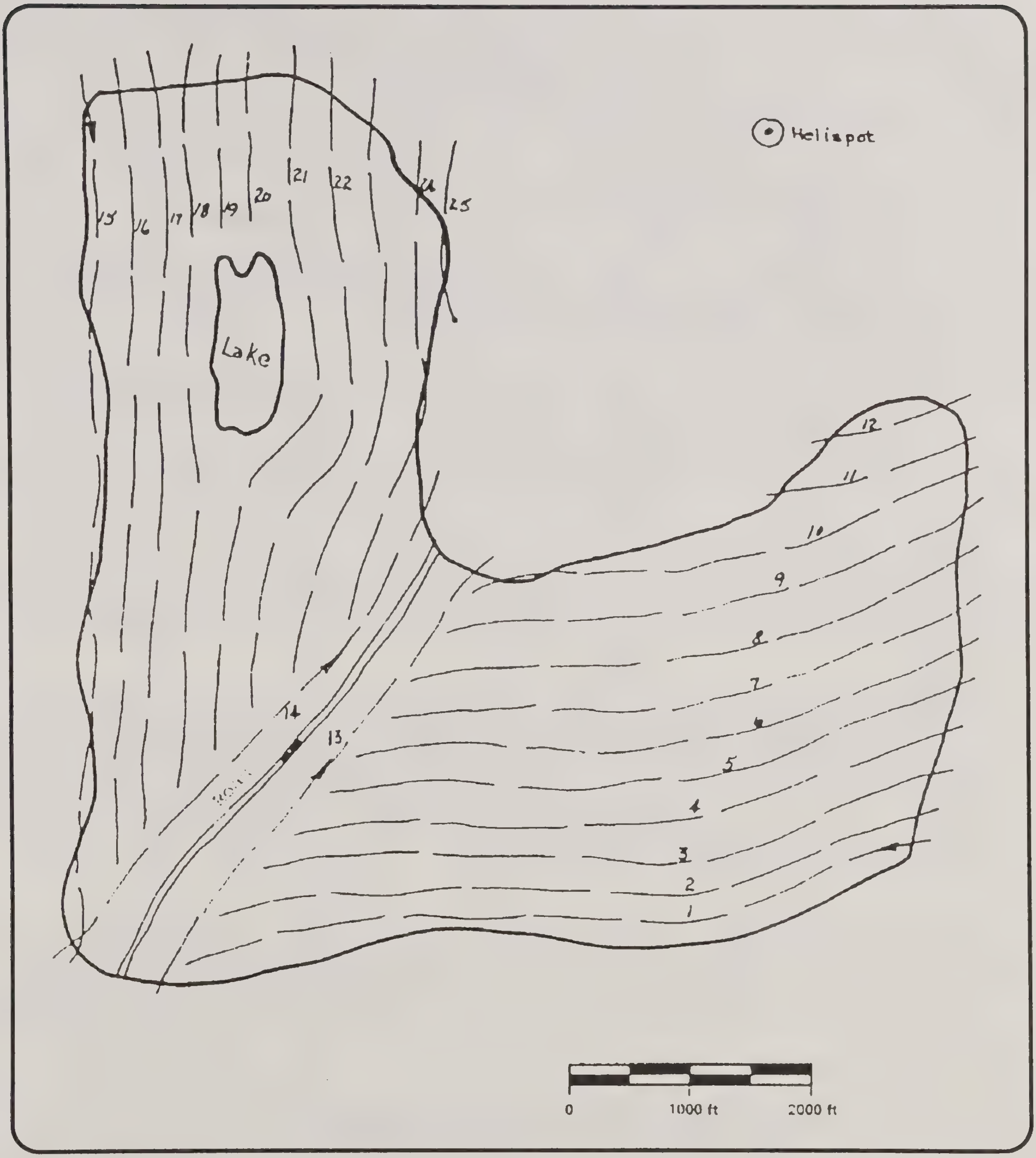


Figure 2.–Example of spray path designation.

It is assumed that the items and values listed below are available or are known:

1. A topographic map showing the target area and the surrounding area.
2. A drawing to a scale sufficient to permit the simultaneous location of helispots and/or airfields and the target area.
3. The pesticide application rate, the pesticide tank capacity, and the spray speed of the aircraft.
4. The loading time per cycle.
5. The hourly costs of spraying, ferrying, loading the pesticide, and turning.

The calculations of the productivity and the efficiency are based upon the following set of assumptions:

1. The amount of pesticide carried each spray cycle is the same.
2. The spray swath width is the same for each spray swath.
3. The operations accounted for in the cost estimate are:
   a. Loading and fueling the aircraft.
   b. Ferrying the aircraft to and from the loading strip and between swaths.
   c. Spraying and touching up.
   d. Turning.
4. The aircraft is loaded and fueled at the local airstrip or pad. Loading time is defined to be the time from "wheels down" to the time of "wheels off".
5. The total touch-up time is directly proportional to the sum of the spraying and the turning times.
6. The decision to terminate a spray cycle is independent of the fuel supply and the fuel consumption rate of the aircraft. Terminating a spray cycle is due solely to the exhaustion of the pesticide contained in the spray tank.
7. No allowance is made for the fact that the final load of the operation may only be partially used. Thus, the time required to spray the last load is the time required to spray the full load.

A complete development of the calculation of each of the times listed in figure 1 together with the description of the costs and the method of constructing the designated flight paths for a spray area of arbitrary shape, topography, and environmental constraints is presented in Banaugh (1984). A copy of this paper is quite helpful for optimum use of CASPR.

CASPR requires an IBM PC-XT (or compatible) with at least 512K of RAM. CASPR supports a Microsoft mouse but its use is not required. A description of CASPR, together with documentation and a set of operational instructions, may be obtained from the developers (See Teske 1988). The program is designed to specifically be "user friendly" and makes use of two main menus that permit the user to easily select functions and options that are available in the program. There is also an extensive HELP menu whose use enables the user to readily become operationally familiar with the program. Results are displayed graphically and clearly labeled. The program, along with some typical examples, is available on a single floppy disk.

The program opens with a brief description of the calculation and the available menus. The main menu and worksheet menu are shown in Figures 3 and 4 respectively. Depending upon the particular spray operation, the user then selects the desired data worksheets and completes them in accordance with the instructions accompanying the worksheet. Figures 5 and 6 respectively depict a completed spray area worksheet and a general data worksheet for a very simple spray area.

Main Menu

Enter Data	**Write Data To File**
Review Calculations	**Help**
Read Data From File	**Exit to DOS**

Figure 3.–Main menu.

Worksheet Menu

General Data Worksheet	Settings
Spray Area Worksheet	Units = *ENGLISH*
Ferry Distance Worksheet	Spray Area Shape = *RECTANGULAR*
Calculate Results	
Change Units of Measure	
Change Spray Area Shape	
Help	
Main Menu	

General Data	– relates to aircraft, spray system, cost, time.
Spray Area	– defines spray area shape and spray path data.
Ferry Data	– relates to ferrying aircraft from/to local base.
Calculate Results	– performs final calculations and displays results.
Change Units	– toggles unit system between English and Metric.
Change Spray Area	– toggles shape between retangular and irregular.
Help	– gives more help on what to do.
Main Menu	– goes back to the main menu.

Figure 4.–Worksheet menu.

Rectangular Spray Area Worksheet

Length/Width Worksheet

Length:	3.375 Miles
Width:	1.75 Miles

Figure 5.–Rectangular spray area worksheet.

General Data Worksheet

Application Rate:	*1.5 gal/acre*	Touchup Constant:	*.1*
Tank Capacity;	*275 gallons*	Spraying Cost Rate:	*200 $/hour*
Swath Width:	*75 feet*	Ferrying Cost Rate:	*200 $/hour*
Spray Speed:	*90 mph*	Turning Cost Rate:	*200 $/hour*
Ferry Speed:	*90 mph*	Touchup Cost Rate:	*200 $/hour*
Turning Time:	*36 seconds*	Loading Cost Rate:	*200 $/hour*
Aux. Ferry Distance:	*90 miles*	Loading Time/Cycle:	*15 minutes*
Number Aux. Turns:	*2*		

Figure 6.–General data worksheet.

The user has the option of printing out a copy of the data worksheets for reference. Upon completing the data worksheets, CASPR calculates and displays the results. Figure 7 is such a display and Figure B depicts a breakdown of the results. Figure 9 is a graphical display of the various times and costs.

Calculation Summary

Total Operation Cost:	*$2769.33*	**Total Flying Cost:**	*$1719.33*
Total Operation Time:	*830. 8 min*	**Total Loading Cost:**	*$1050.00*
Cost Per Unit Time:	*$200.00/hcur*	**Total Flying Time:**	*515.8 min*
Cost Per Unit Area:	*$.73/acre*	**Total Loading Time:**	*315 min*
Productivity:	*272.99 acre/hour*		
Efficiency:	*37.92%*		

Figure 7.–Calculation Summary.

Calculation Breakdown

Total Spray Area:	*3780 acres*	**Spraying Time:**	*277.2 min*
Material Flow Rate:	*20.45 gal/min*	**Ferrying Time;**	*100 min*
		Turning Time:	*100.8 min*
Spray Cycle Distance:	*20.17 miles*	**Touchup Time:**	*37.8 min*
Number of Spray Cycles:	*21*	**Total Flying Time:**	*515.8 min*
Total Spray Distance:	*415.8 miles*		
Number of Spray Turns:	*124*		
Number of Ferry Turns:	*42*		
Number of Aux. Turns:	*2*		
Total Number of Turns:	*168*		

Figure 8.–Calculation breakdown.

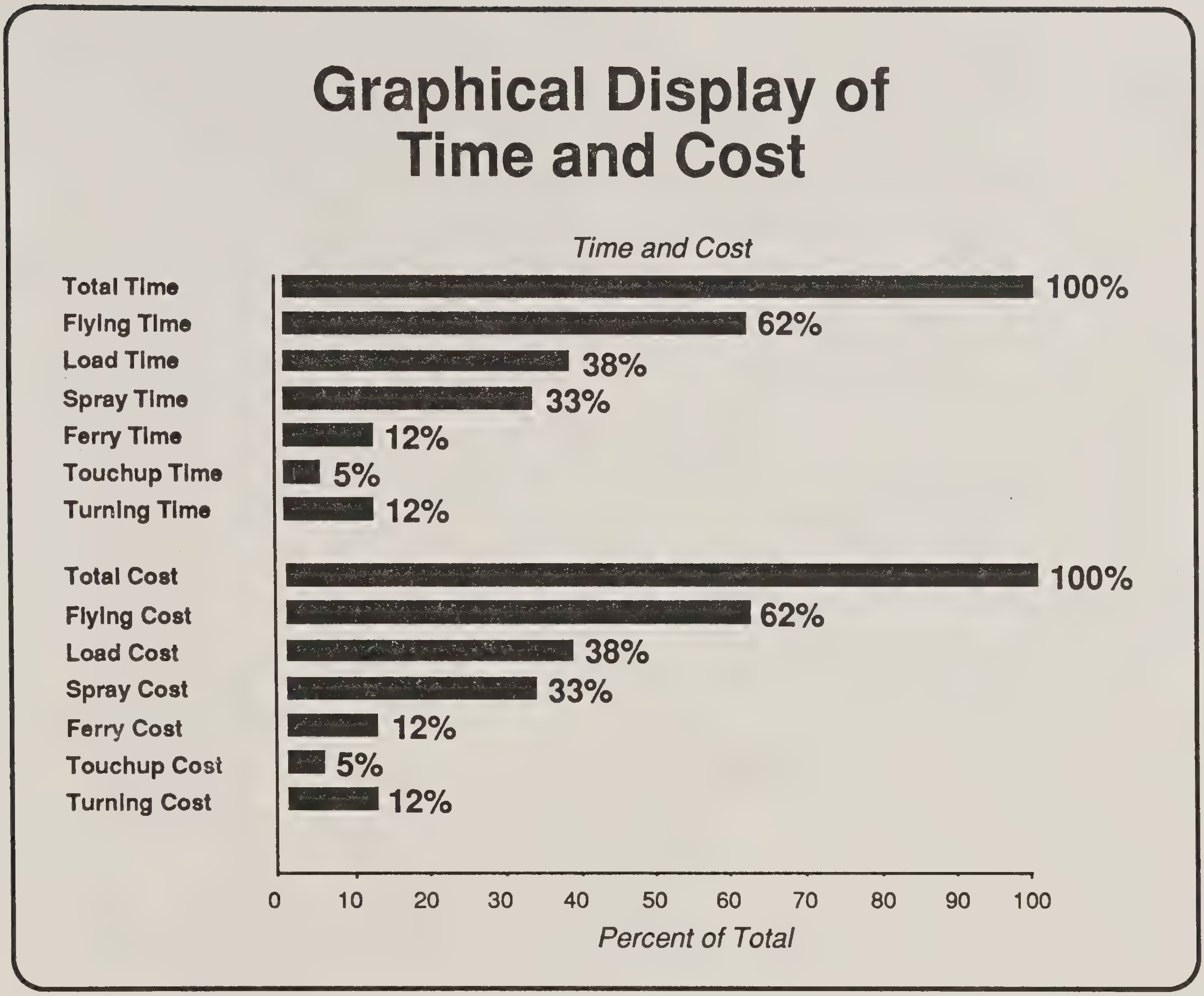
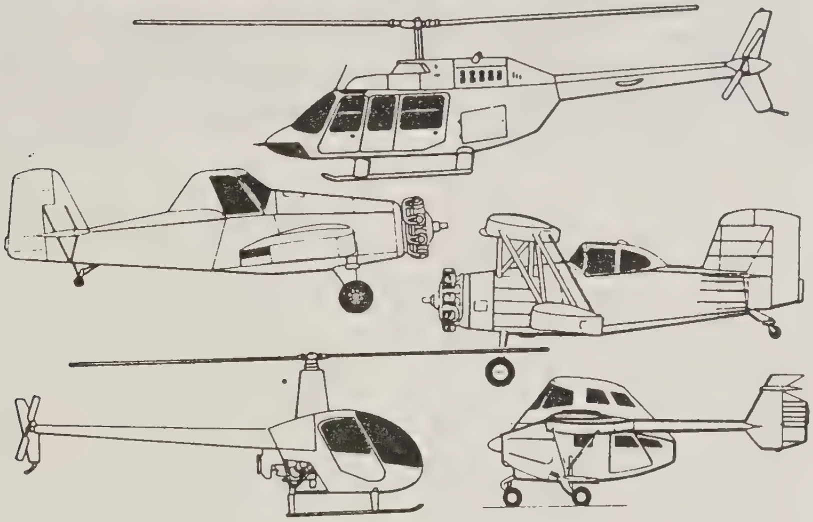


Figure 9.–Display of time and cost.

In summary, CASPR is a versatile tool for analyzing the effectiveness and efficiency of the design of a particular aerial spray operation. The effect of altering a specific plan may be readily determined. For example, an examination of the results of runs corresponding to the use of different spray path widths or different application rates can enable the determination of the optimum spray path widths and/or application rates. By examining the results of such parameter alterations, the spray tactics designer can optimize the effectiveness of the spray operation. CASPR allows the altered data worksheet files to be saved so that corresponding data and results may again be used or examined at a later time. CASPR is easy to use, requires minimal PC capability and will be available from the developers and/or the USDA Forest Service, Missoula Technology and Development Center.

APPENDIX D

A Method for Comparing Cost & Productivity of Aerial Spray Delivery



By
Robert Banaugh
Mechanical Engineer

Project Leader:
Robert Ekblad
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November 1984
3400—Forest Pest Management
8434 2807

ABSTRACT

An integral part of the Forest Service Insect and Disease Program is the design of aerial spray programs. Designing such programs requires a method of evaluating and comparing aerial spray strategies. This report defines measures of evaluation and comparison and develops a method for calculating these quantities. The report includes worksheets, sample problems, and the derivation of the necessary equations to assist Forest managers and others who are responsible for designing and evaluating aerial spray operations.

A report on Technological Improvements (TI) Project 3E32P44, Spray Deposit Assessment, sponsored by the Forest Pest Management Staff and State and Private Forestry.

CONTENTS

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

INTRODUCTION

In an aerial spray operation, an aircraft applies a pesticide to a specific target, usually an insect or plant infestation. Because forest target areas (fig. 1) are large, inaccessible, and remote, spraying is a major task that requires preparation and planning. Planning requires the ability to compare spray delivery systems. This report presents methods that will enable the Forest manager to make such comparisons.

Two measures of effectiveness of the delivery of an aerially applied spray are the <u>spray productivity</u> and the <u>spray efficiency</u>. Spray productivity is the area sprayed per hour and is the quotient of the area sprayed divided by the total operational time. Spray efficiency is the ratio of the actual spraying-time to the total-operational-flying-time.

This report presents a procedure for calculating both measures of effectiveness. Readers may select the measure most appropriate for their spray operations. An example of the use of the procedure as a planning aid is also presented.

The estimation of the productivity, efficiency, and cost of an aerial spray operation is based upon an accounting of the completion times of the various phases of the spray operation. These times and their interrelationship are shown in figure 2.

Total Operational Time	=	Flying Time	+	On the Ground Time				
Flying Time	=	Ferrying Time	+	Spraying Time	+	Turning Time	+	Touchup Time
On the Ground Time	=	Loading Time	+	Equipment Adjustment or Repair Time	+	Aircraft Repair Time		

Figure 2.--Operational times and their relationship.

The calculation of the times requires a specification of the flight paths. This specification must be made with due recognition of the variation in topography and the environmental constraints. As a result, the flight paths are usually curved and not all of the same length. This is in contrast to the straight spray paths that usually characterize spraying food crops where the target areas tend to be flat, of uniform height, and rectangular in shape. The determination of the flight time required to spray a forest target must take into account the variation in spray path lengths. This report presents a modification of the Baltin-Amsden[1] method of calculating the efficiency, the productivity, and the cost of an aerial spray operation. The modification allows for irregularly shaped and topographically varied target areas.

1/ Amsden, R. C. (1959). The Baltin-Amsden Formula. Agricu. Aviat. 2(3),95.

Figure 1.--Example of forest target area.

Some costs are not included in the efficiency and the productivity calculations. These costs are due to: ground transportation of fuel and pesticide, equipment maintenance, rental and/or purchase of equipment and supplies, personnel, services, overhead, evaluation, and administration. Because these costs are not accounted for in the calculation, the results should be used to compare only the direct operational spraying costs for different spray tactics.

NOTATION

a_r = pesticide application rate, in gallons per acre or in liters per hectare

A_s = area to be sprayed, in acres or hectares

c_r = conversion constant in pesticide flow rate calculation

c_s, c_f, c_ℓ, c_t, and c_u = the hourly costs of spraying, ferrying, loading, turning, and touching up respectively

C_ℓ, C_o = the total costs of loading and flying respectively

C_T = total operation cost

d_a = total auxiliary ferrying distance from permanent airbase to or from helispot, in miles or kilometers

d_f = ferry distance from spray area to or from helispot or airbase for a given cycle, in miles or kilometers

D_f = total direct spray ferry distance, for all cycles from helispot or airbase to and from spray cycle areas, in miles or kilometers

d_s = spray distance in a single cycle, in miles or kilometers

D_s = total spray distance, in miles or kilometers

EFF= efficiency of spraying, i.e., the ratio of the actual-spraying-time to the total-operational-spraying-time, in percent

f_r = pesticide aircraft spray system flow rate, in gallons per minute or in liters per minute

k_u = proportionality constant relating the touchup time to the sum of the total spraying time and the total turning time; usually, $k_u = 0.1$

L= length of rectangular spray area in miles or kilometers

N_a= number of turns used in auxiliary flying

N_c= total number of spray cycles

N_f= number of turns required in ferrying

N_s= number of turns required to spray the target area

N_t= total number of turns required to complete the aerial spray operation

PROD= productivity in acres or hectares sprayed per hour

R_t= operation cost per hour

R_a= operation cost per acre or per hectare

Q_f= pesticide tank capacity, in gallons or liters

s_w= swath width, in feet or meters

T_f= total ferry time, in minutes

T_o= total actual flying time, in minutes

t_ℓ= average time to load and refuel between spray cycles, in minutes

T_ℓ= total loading time, in minutes

T_s= total actual spraying time, in minutes

T_t= total turning time while spraying, in minutes

t_t= time to make a single turn, in seconds

T_T= total operation time, in minutes

T_u= total touchup time, in minutes

v_f= ferry airspeed, in miles per hour or kilometers per hour

v_s= spray airspeed, in miles per hour or kilometers per hour

W= width of rectangular spray area in miles or kilometers

ASSUMPTIONS

It is assumed that the items and the values of the variables listed below are available or known:

1. A topographic map showing the target and the surrounding area.

2. A drawing to a scale sufficient to permit the simultaneous location of helispots and/or airfields and the target area.

3. The pesticide application rate, a_r; the pesticide tank capacity, Q_f; and the spray speed of the aircraft, v_s.

4. The loading time per cycle, t_ℓ.

5. The hourly costs of spraying, c_s; ferrying, c_f; loading, c_ℓ; and turning, c_t.

The calculations of the productivity and the efficiency are based on the assumptions that:

1. The amount of pesticide carried each cycle is the same.

2. The swath width, s_w, is the same for each swath.

3. The operations accounted for in the cost estimate are:

   a. Loading and the fueling of the aircraft.

   b. Ferrying of the aircraft to and from the loading strip and between swaths (if necessary).

   c. Spraying and touching up.

   d. Turning.

4. The aircraft is loaded and fueled at the local strip or pad. Loading time is defined to be the time from "wheels down" to the time of "wheels off."

5. The total touch time, T_u, is directly proportional to the sum of the spraying and the turning times.

6. The decision to terminate a spray cycle is independent of the fuel supply and the fuel consumption rate of the aricraft. Terminating a spray cycle is due solely to the exhaustion of the pesticide contained in the spray tank.

7. No allowance is made for turning time when calculating the touchup time.

8. No allowance is made for the fact that the final load of the operation may only be partially used. Thus, the time required to spray the last load is the time required to spray the full load.

TECHNICAL APPROACH

Calculating the spray productivity and the spray efficiency requires the determination of the times required to complete the operations of spraying, ferrying, turning, and loading. In this report only these operations will be accounted for in the determination of the productivity and the efficiency. Spraying is the flying required to actually spray the target area and turning is the flying necessary to realign the aircraft for spraying the succeeding path.

Ferrying is the flying required to fly the spray aircraft from the helispot, local airstrip, or permanent airbase to the spray area and return. Ferrying also includes the nonspray flying necessary to fly from one point in the target area to another without returning to the local base or to the permanent airfield. Such flying is usually done by "jumping" from one portion of the target area to another to again resume spraying. Ferrying also includes flying the aircraft to spots in the target area to begin "touching up" various subareas that may have been missed or omitted.

The determination of the times to complete the various flying operations depends upon the total spray distance, the total ferry distance, the total number of turns, and the total number of loads. In turn, these quantities depend upon the spray path lengths. If the spray area may be suitably approximated by a rectangle and the spray paths are parallel to a side of the rectangle, the spray path length is the length of that side of the rectangle. In this event it is straightforward to determine the total spray path distance.

If the spray area is irregular in shape, the determination of the aforementioned quantities can be made by specifying, on a scaled drawing of the target area, a set of lines which are to be paralleled by the actual spray paths. In the following, these lines will be called spray lines to distinguish them from the actual flight (spray) paths. Figure 3 indicates a typical situation and the dashed lines are spray lines. The actual spray paths are to be flown parallel to and between the spray lines and hence between any pair of adjacent spray lines there may be one or more spray paths. The spray lines are assumed to be drawn close enough together so that the length of a spray path lying between a pair of adjacent spray lines can be assumed to be the same length as the nearest spray line. In figure 3, the pairs of points Y_s, Y_e; and Z_s, Z_e; indicate the beginning and the ending of the spray lines paralleling the road.

A spray path length can then be determined by measurement of the length of the nearest spray line using the scaled drawing. Numbering the spray lines on the target drawing facilitates the accounting of their length.

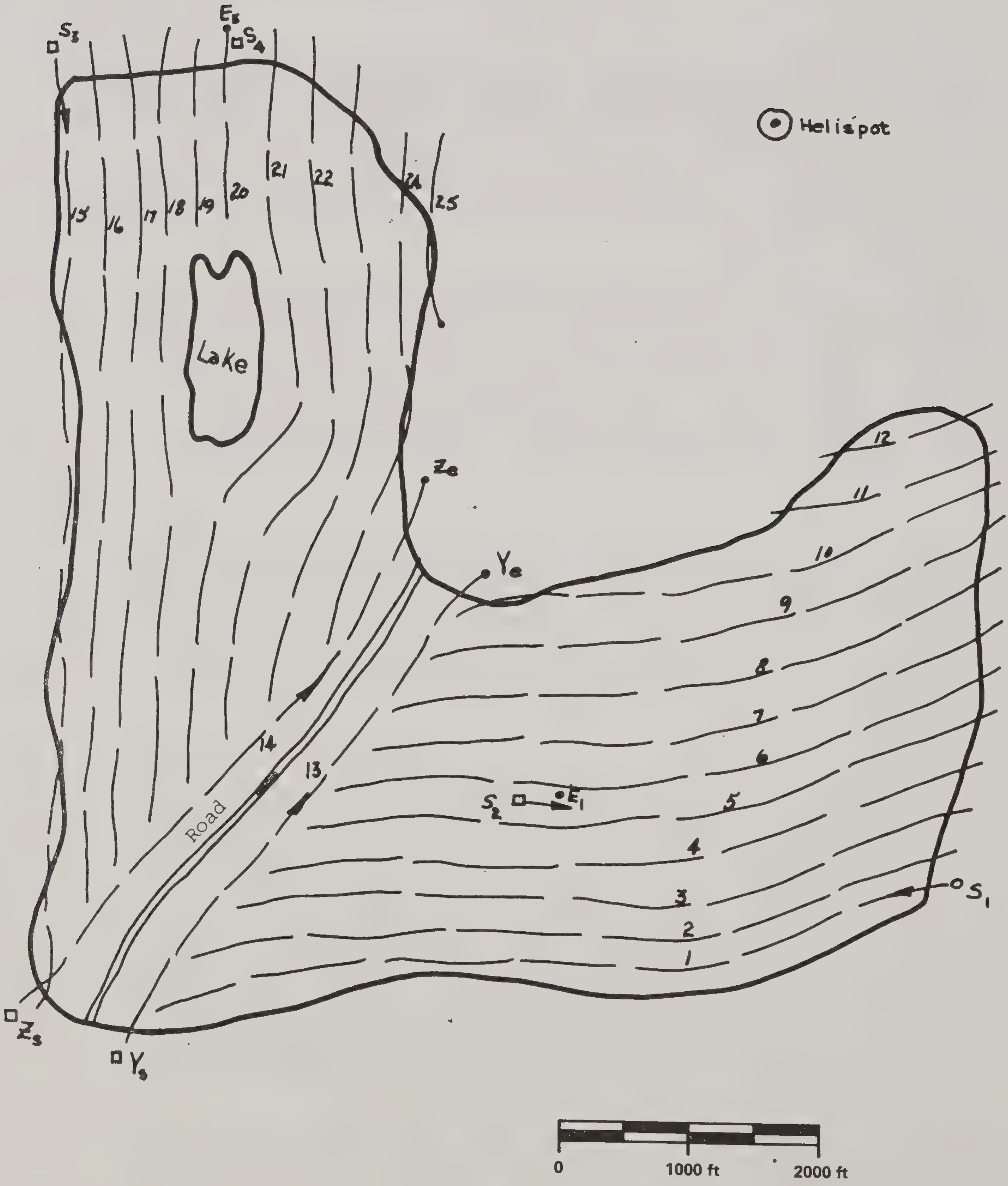

Figure 3.--Example of spray path designation.

CALCULATION PROCEDURE

The following section describes the procedure for calculating the spray efficiency and spray productivity. The procedure is described in some detail to enable the reader to grasp the rationale. The next section consists of a set of blank worksheets that are to be used in their numerical order when performing the calculations. Following the blank worksheets are three completed examples illustrating the calculations and the use of the worksheets in carrying out the calculations.

Step 1.

Determine the area to be sprayed, A_s, in acres or hectares.

A_s can be determined from the scaled drawing.

Step 2.

Determine the spray characteristics and specify the spray equipment to be used in the operation.

The allowable EPA registered pesticides and the application rate are specified by the Forest entomologist. The spray strategist recommends the droplet size distribution and then selects the aircraft type and the associated spray equipment and spray parameters. After the spray parameters have been set, the swath width, s_w, is determined. Assuring the swath width may require preliminary tests.

Step 3.

On a scale drawing of the target area, draw the spray lines. The lines should be drawn with proper regard for topography, local meterological conditions, and such environmental constraints as rivers, creeks, campsites, lakes, etc. Other areas in or near the target area not to receive spray should be clearly identified.

Step 4.

Determine the required pesticide flow rate for the aircraft spray system.

The pesticide flow rate in gallons/minute is given by:

$$f_r = \frac{a_r v_s s_w}{495}$$

The pesticide flow rate in liters/minute is given by:

$$f_r = \frac{a_r v_s s_w}{600}$$

Step 5.

Determine the allowable spray cycle distance, d_s, for each of the spray cycles. d_s is specified in miles or kilometers and is governed by the spray tank capacity, the speed of the aircraft while spraying, and the pesticide flow rate.

The spray distance per cycle in miles or kilometers is:

$$d_s = \frac{Q_f v_s}{60 f_r}$$

Note: The units of the quantities appearing in the above formula must be compatible.

Step 6.

Determine the total spray path length, D_s.

For rectangular-shaped target areas, the number of spray paths is the quotient of the length of the side of the rectangle perpendicular to the spray path divided by the swath width. This number, multiplied by the spray path length, is the total spray distance.

For irregularly shaped target areas, the total length of the spray paths is found by summing the lengths of all spray paths. The number of such paths is that required to cover the target area and is the sum of the numbers of spray paths required to cover the areas between pairs of adjacent spray lines. Each of these numbers is the quotient of the average distance between the pair of adjacent spray lines and the swath width. [These numbers are entered in the appropriate rows of the second column of the table accompanying item 6 (page 19) on the set of worksheets.] The average distance between any pair of adjacent spray lines can be estimated with the aid of a ruler and the scaled drawing of the target area.

The length of the spray path is assumed to be the same length as the length of its nearest neighbor spray line. The length of a spray line may be obtained by measurement from the scaled drawing.

For rectangular-shaped target areas as well as for irregularly shaped target areas, the product of the total length of the spray path and the swath width should be equal to the area of the target. Thus, a comparison of this product with the actual target area provides a measure of the accuracy of the determination of D_s.

Near the end of the spray cycle, the flow rate of the pesticide decreases due to the near emptiness of the pesticide tank. This results in a lesser pesticide dose being sprayed on the end portion of the cycle. The proper dose is assured by respraying the affected portion of the cycle. In the calculation of D_s, no allowance was made for this duplication of spraying. The user may wish to correct for this omission by increasing the calculated value of D_s by an amount proportional to the calculated value.

Step 7.

Determine the number of spray cycles, N_c. N_c is the rounded up quotient of the total spray path length by the spray cycle distance.

$$N_c = \frac{D_s}{d_s}$$

Step 8.

Determine the total spray cycle ferry distance, D_f.

D_f is the sum of the distances, d_f, from the helispot or airport to the starting and ending points of the spray cycles. If the nearby temporary helispots are used, determine the ferry distance from the helispot to the permanent helicopter base. Denote this auxiliary ferry distance by d_a and include this distance in the previous sum. D_f should also include the distances required to ferry the aircraft from one point in the target area to another while not actually spraying. Such flying is usually done when "hopping" from one area to another to touch up the spray area. All of the distances should be obtainable from the scaled spray area layout.

The estimation of the ferry distances to the starting and ending points of a spray cycle requires the location of these points. These locations may be determined by summing successive spray path lengths until the spray cycle distance is obtained. The point on the spray path where this occurs is taken to be the end point of the spray cycle. The summing process can be accomplished most readily with the aid of a ruler and the scaled drawing. The spraying of an area usually requires many spray cycles. Thus errors made in determining the total ferry distance, which is the sum of the ferry distances to and from each starting and ending point, should "average out."

Item 8 (page 21) of the worksheet set provides a tabular form for recording the ferry distances.

Step 9.

Determine the total number of turns, N_t.

N_t is the total number of turns required to complete the aerial spray operation. N_t is the sum of: N_s, the number of turns required to spray the target area; N_f, the number of turns required in ferrying; and N_a, the number of turns used in auxiliary flying such as touching up, observation, etc. N_s is equal to the number of spray paths, N_f may be taken to be twice the number of cycles, and N_a is an ad hoc estimate. N_a may be zero. In the event any of the numbers are not integers, they are to be rounded up. For a rectangular shaped spray area the default value for N_a is 2, which allows for a bit of touching up.

Step 10.

Determine the total ferry time, T_f, the total spray time, T_s, and the total turning time, T_t. These items are each measured in minutes.

T_f is given by

$$T_f = 60 \left(\frac{d_f + d_a}{v_f} \right)$$

T_s is given by

$$T_s = 60 \left(\frac{D_s}{v_s} \right)$$

Note: T_s does not include touchup time. This time is calculated in Step 11 below.

T_t is given by

$$T_t = \frac{N_t t_t}{60}$$

Note: The units of the quantities appearing in each of the above equations must be compatible.

Step 11.

Determine the total touchup time, T_u. T_u is assumed to be proportional to the sum of the total actual spraying time and the total turning time.

T_u is measured in minutes and is given by

$$T_u = k_u \, (T_s + T_t)$$

where k_u is usually taken to be 0.1. The value of k_u may be altered to better reflect the local conditions.

Step 12.

Determine the total loading time, T_ℓ. T_ℓ is measured in minutes and is the product of the total number of cycles and the average loading time per cycle.

$$T_\ell = N_c \, t_\ell$$

Step 13.

Determine the total actual flying time, T_o. T_o is measured in minutes and is given by

$$T_o = T_f + T_s + T_t + T_u$$

Step 14.

Determine the total operation time, T_T. T_T is measured in minutes and is the sum of the total flying time and the loading time.

$$T_T = T_o + T_\ell$$

Step 15.

Determine the total flying cost, C_o. C_o is calculated in terms of the specified hourly costs of spraying, ferrying, turning, and touching up.

$$C_o = (c_s \, T_s + c_f \, T_f + c_t \, T_t + c_u \, T_u) \, /60$$

Step 16.

Determine the total loading cost, C_ℓ.

This cost is determined by the total loading time and the average hourly cost of loading.

$$C_\ell = (T_\ell \, c_\ell)/60$$

Step 17.

Determine the productivity, PROD.

PROD is the ratio of the total area sprayed to the total operation time. PROD is measured in acres per hour or hectares per hour.

$$PROD = 60 \, A_s/T_T$$

Step 18.

Determine the efficiency, EFF.

EFF is measured in percent and is the ratio of the total actual spraying time to the total operation time.

$$EFF = 100 \, (T_s + T_u)/T_T$$

Step 19.

Determine the total cost, C_T.

$$C_T = C_o + C_\ell$$

Step 20.

Determine the hourly operation cost, R_t.

R_t is the quotient of the total cost by the total time.

$$R_t = 60 \, C_T/T_T$$

Step 21.

Determine the cost per acre or the cost per hectare, R_a.

R_a is the quotient of the total cost by the total area sprayed.

$$R_a = C_T/A_s$$

INSTRUCTIONS FOR USING WORKSHEET SET

1. Complete Input Data Sheet.

2. Complete calculations in Worksheet Set (pages 17-23).

The calculations are to be done in the order they appear on the worksheet page. The number preceding the individual calculation title refers to the corresponding step number described in the procedure section.

3. If several areas are to be sprayed in the same operation and such parameters as swath width, application rate, flying speeds, costs, etc. are different for each area, it will be necessary to use a separate copy of the complete worksheet set for each spray area, or set of spray areas, that are operationally defined by the different sets of parameters.

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	______
Target Dim**	mi or km	L, W	______
Application Rate	g/Ac or l/ha	a_r	______
Tank Capacity	g or l	Q_f	______
Swath Width	ft or m	s_w	______
Spray Speed	mi/hr or km/hr	v_s	______
Ferry Speed	mi/hr or km/hr	v_f	______
Turning Time	sec	t_t	______
Aux. Ferry Dis.	mi or km	d_a	______
Touchup Const. of Prop.		k_u	______
Spraying Cost Rate	$/hr	c_s	______
Ferrying Cost Rate	$/hr	c_f	______
Turning Cost Rate	$/hr	c_t	______
Touchup Cost Rate	$/hr	c_u	______
Loading Cost Rate	$/hr	c_ℓ	______
Loading Time/Cycle	min	t_ℓ	______

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = ______________________________ ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\_\_\_\_\_)\ (\_\_\_\_\_) = \_\_\_\_\_$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_\_)\ (\_\_\_\_\_) = \_\_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (\_\_\_\_\_)\ (\_\_\_\_\_)\ (\_\_\_\_\_)\ (\_\_\_\_\_)$

f_r = _________________________ g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(\qquad)\ (\qquad)}{60(\qquad)}$$

d_s = _________________________ mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = ____________________ mi or km

Rectangular shaped spray area

$$D_s = K\left(\frac{W}{s_w}\right)L = \frac{(\quad\quad)\ (\quad\quad)}{(\quad\quad)}\ \underline{(\quad\quad)}$$

D_s = __________________ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(\quad\quad\quad\quad)}{(\quad\quad\quad\quad)}$$

N_c = ________________________________

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
		Total (for item 9) N_s =	Sum (ft or m) D_s =
		Tot. No. Paths =	Sum* (mi or km) D_s =
			Tot. D_s =

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
Totals			

D_f = Sum of the totals.

= ______ + ______ + ______

D_f = ______ mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums.

N_s = ______________

$N_f = 2N_c = 2$ (______) = ______, and N_a = ______

$N_t = N_s + N_f + N_a$ = (______) + (______) + (______)

N_t = ______________

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w} = \frac{(\_\_\_\_\_\_)\ (\_\_\_\_\_\_)}{(\quad\quad)}$ = ______ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (______) = ______, and N_a = ______________

$N_t = N_s + N_f + N_a$ = (______) + (______) + (______)

N_t = ______________

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60\,\frac{(D_f + d_a)}{v_f} = 60\,\frac{(\_\_\_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_\_)}{(\quad\quad)}$$

T_f = ______________ min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60\frac{D_s}{v_s} = 60\left(\frac{\quad}{\quad}\right)$$

T_s = ______________ min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\_\_\_\_\_\_)\ (\_\_\_\_\_)\ /60$$

$$T_t = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\_\_\_\_\_\_)\ \ (\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_)$$

$$T_u = \_\_\_\_\_\_\_\_\_ \text{min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\_\_\_\_\_)\ (\_\_\_\_\_)$$

$$T_\ell = \_\_\_\_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\_\_\_\_\_) + (\_\_\_\_\_) + (\_\_\_\_\_) + (\_\_\_\_\_)$$

$$T_o = \_\_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\_\_\_\_\_) + (\_\_\_\_\_)$$

$$T_T = \_\_\_\_\_\_\_\_\_\_\_\_\_ \text{min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \Big[(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)+(\_\_\_\_)(\_\_\_\_)\Big]/60$$

$$C_o = \_\_\_\_\_\_\_\_ \text{dollars}$$

Step 16. Total Loading Cost, C_ℓ

$$C_\ell = (T_\ell c_\ell)/60 = \frac{(\_\_\_\_)}{60}(\_\_\_\_)$$

C_ℓ = __________dollars

Step 17. Productivity, PROD

$$PROD = 60\ A_s/T_T = 60\ (\_\_\_\_)\ /\ (\_\_\_\_)$$

PROD = ____________ac/hr or ha/hr

Step 18. Efficiency, EFF

$$EFF = 100\quad (T_s + T_u)/T_T = 100\ (\_\_\_\_\_ + \_\_\_\_\_)/(\_\_\_\_\_\_)$$

EFF = _____________________%

Step 19. Total Cost, C_T

$$C_T = C_o + C_\ell = (\_\_\_\_\_) + (\_\_\_\_\_)$$

C_T = ___________dollars

Step 20. Total Operation Cost/Hour, R_t

$$R_t = 60\ C_T/T_T = 60\ (\_\_\_\_)\ /\ (\_\_\_\_)$$

R_t = _____\$/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$$R_a = C_T/A_s = (\_\_\_\_)/(\_\_\_\_)$$

R_a = _________\$/ac or \$/ha

Example No. 1

Use of the Rectangular Approximation

Assume that a single helicopter is used to spray an area which may be approximated by a rectangle. The area is to be sprayed from a helispot adjacent to the spray area and the following data is prescribed:

1. The direct ferry distance, d_f is 30 miles.

2. The total auxiliary ferry distance, d_a is 90 miles.

3. A single cycle is required to spray the area, and the spray path is parallel to the longest side of the rectangle.

4. The remaining prescribed data is as given on the input data sheet (see page 25). Because target is rectangular in shape, no layout is needed. It is assumed that the ferry distances from the local base to the starting point and from the ending point to the local base are the same.

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	
Target Dim**	mi or km	L, W	3 3/8 x 1 3/4 mi
Application Rate	g/Ac or l/ha	a_r	1.5 g/Ac
Tank Capacity	g or l	Q_f	275 g
Swath Width	ft or m	s_w	75 ft
Spray Speed	mi/hr or km/hr	v_s	90 mi/hr
Ferry Speed	mi/hr or km/hr	v_f	90 mi/hr
Turning Time	sec	t_t	36 sec
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.1
Spraying Cost Rate	\$/hr	c_s	200 \$/hr
Ferrying Cost Rate	\$/hr	c_f	200 \$/hr
Turning Cost Rate	\$/hr	c_t	200 \$/hr
Touchup Cost Rate	\$/hr	c_u	200 \$/hr
Loading Cost Rate	\$/hr	c_ℓ	200 \$/hr
Loading Time/Cycle	min	t_ℓ	15 min

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = ______________ Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\underline{3\ 3/8})\ (\underline{1\ 3/4}) = \underline{3780}$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (\underline{0.00202})\ (\underline{1.5})\ (\underline{90})\ (\underline{75})$

f_r = $\underline{20.45}$ g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(275)\ (90)}{60\,(20.45)}$$

d_s = $\underline{20.17}$ mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = ______________________ mi or km

Rectangular shaped spray area

$$D_s = K \left(\frac{W}{s_w}\right) L = \frac{(5{,}280)}{} \; \frac{(3\tfrac{3}{8})}{(75)} \; \frac{(1\tfrac{3}{4})}{}$$

D_s = 415.8 mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(415.8)}{(20.17)}$$

N_c = 21

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
		Total (for item 9) N_s =	Sum (ft or m) D_s =
		Tot. No. Paths =	Sum* (mi or km) D_s =
			Tot. D_s =

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	30	30	0
Totals			

D_f = Sum of the totals.

= 30 + 30 + 0

D_f = 60 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = ______________

$N_f = 2N_c = 2$ (______) = ______, and N_a = ______

$N_t = N_s + N_f + N_a$ = (______) + (______) + (______)

N_t = ______________

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w} = \frac{(5280)(1\frac{3}{4})}{(75)} = 124$ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (21) = 42, and N_a = 2

$N_t = N_s + N_f + N_a$ = (124) + (42) + (2)

N_t = 168

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{60 + 90}{(90)} \right)$$

T_f = 100 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{415.8}{90} \right)$$

T_s = 277.2 min

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{168})\ (\underline{36})\ /60$$

$$T_t = \underline{100.8} \text{ min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\underline{0.1})\ (\underline{277.2} + \underline{100.8})$$

$$T_u = \underline{37.8} \text{ min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\underline{21})\ (\underline{15})$$

$$T_\ell = \underline{315} \text{ min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{277.2}) + (\underline{100}) + (\underline{100.8}) + (\underline{37.8})$$

$$T_o = \underline{515.8} \text{ min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{515.8}) + (\underline{315})$$

$$T_T = \underline{830.8} \text{ min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{200})(\underline{277.2}) + (\underline{200})(\underline{100}) + (\underline{200})(\underline{100.8}) + (\underline{200})(\underline{37.8})\right]/60$$

$$C_o = \underline{1719.33} \text{ dollars}$$

Step 16. Total Loading Cost, C_ℓ

$$C_\ell = (T_\ell c_\ell)/60 = \frac{(\underline{315})}{60}\ (\underline{200})$$

$$C_\ell = \underline{1{,}050} \text{ dollars}$$

Step 17. Productivity, PROD

$$\text{PROD} = 60\ A_s/T_T = 60\ (\underline{3780})\ /\ (\underline{830.8})$$

$$\text{PROD} = \underline{273} \text{ ac/hr or ha/hr}$$

Step 18. Efficiency, EFF

$$\text{EFF} = 100\quad (T_s + T_u)/T_T = 100\ (\underline{277.2} + \underline{37.8})/(\underline{830.8})$$

$$\text{EFF} = \underline{37.9}\ \%$$

Step 19. Total Cost, C_T

$$C_T = C_o + C_\ell = (\underline{1{,}719.33}) + (\underline{1050})$$

$$C_T = \underline{2{,}769.33} \text{ dollars}$$

Step 20. Total Operation Cost/Hour, R_t

$$R_t = 60\ C_T/T_T = 60\ (\underline{2{,}769.33})\ /\ (\underline{830.8})$$

$$R_t = \underline{200}\ \$/\text{hr}$$

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$$R_a = C_T/A_s = (\underline{2{,}769.33})/(\underline{3780})$$

$$R_a = \underline{0.73}\ \$/\text{ac or }\$/\text{ha}$$

Example No. 2

Assumptions

1. The area to be sprayed is that shown in figure 3.

2. The number of spray cycles is to be estimated from a scale drawing depicting the spray lines. Each of the spray lines corresponds to approximated actual spray paths.

3. A single helicopter is to be used. It is to be flown from the nearby helispot indicated in figure 3.

4. The helicopter is to be ferried to the helispot from an overnight airbase, a distance of 45 miles. Thus, the auxiliary ferry distance, d_a, is 90 miles.

5. The relevant data for the operation is as shown on the data sheet.

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	715
Target Dim**	mi or km	L, W	
Application Rate	g/Ac or l/ha	a_r	2¼ g/Ac
Tank Capacity	g or l	Q_f	500 g
Swath Width	ft or m	s_w	40 ft
Spray Speed	mi/hr or km/hr	v_s	90 mi/hr
Ferry Speed	mi/hr or km/hr	v_f	150 mi/hr
Turning Time	sec	t_t	15
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.2
Spraying Cost Rate	$/hr	c_s	300
Ferrying Cost Rate	$/hr	c_f	250
Turning Cost Rate	$/hr	c_t	250
Touchup Cost Rate	$/hr	c_u	300
Loading Cost Rate	$/hr	c_ℓ	150
Loading Time/Cycle	min	t_ℓ	20

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = 715 Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (0.00202)\ (2\tfrac{1}{4})\ (90)\ (40)$

f_r = 16.36 g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(500)\ (90)}{60\,(16.36)}$$

d_s = 45.84 mi or km

> Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = 147.3 mi or km

Rectangular shaped spray area

$$D_s = K\left(\frac{W}{s_w}\right)L = \frac{(\quad)}{}\ \frac{(\quad)}{(\quad)}\ \frac{(\quad)}{}$$

D_s = __________ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km or m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(147.3)}{(45.84)}$$

N_c = 4

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
1	6,500	6	39,000
2	6,000	6	36,000
3	5,750	8	46,000
4	5,750	7	40,250
5	5,500	6	33,000
6	5,300	7	37,100
7	4,850	8	38,800
8	4,850	8	38,800
9	4,750	7	33,250
10	4,900	7	34,300
11	1,750	7	12,250
12	1,350	5	6,750
		Total (for item 9) N_s = 82	Sum (ft or m) D_s = 395,500 ft
			Sum* (mi or km) D_s = 74.91 mi

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Example 2

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
13	4,750	7	33,250
14	5,250	7	36,750
15	7,500	5	37,500
16	6,750	5	33,750
17	6,500	6	39,000
18	6,250	7	43,750
19	1,375	6	8,250
20	1,375	7	9,625
21	6,250	8	50,000
22	4,750	7	33,250
23	5,175	7	36,225
24	4,150	4	16,600
25	850	5	4,250
		Total (for item 9) N_s = 81	Sum (ft or m) D_s = 382,200 Ft
		Tot. No. Paths = 163	Sum* (mi or km) D_s = 72.39 mi

Tot. D_s = 147.3 mi

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	1.1	0.9	2
2	0.9	1.1	
3	1.1	0.7	
4	0.7	0.5	
Totals	3.8	3.2	2

D_f = Sum of the totals.

= 3.8 + 3.2 + 2

D_f = 9 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = 163

$N_f = 2N_c = 2$ (4) = 8, and N_a = 2

$N_t = N_s + N_f + N_a$ = (163) + (8) + (2)

N_t = 173

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w}$ = (____) $\frac{(\_\_\_\_)}{(\_\_\_\_)}$ = ______ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (____) = ____, and N_a = ______

$N_t = N_s + N_f + N_a$ = (____) + (____) + (____)

N_t = ______

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{9 + 90}{(150)} \right)$$

T_f = 39.6 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{147.3}{90} \right)$$

T_s = 98.2 min

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*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{173})\ (\underline{15})\ /60$$

$$T_t = \underline{43.25} \text{ min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\underline{0.2})\ (\underline{98.2} + \underline{43.25})$$

$$T_u = \underline{28.3} \text{ min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\underline{4})\ (\underline{20})$$

$$T_\ell = \underline{80} \text{ min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{98.2}) + (\underline{39.6}) + (\underline{43.25}) + (\underline{28.3})$$

$$T_o = \underline{209.35} \text{ min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{209.35}) + (\underline{80})$$

$$T_T = \underline{289.35} \text{ min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{300})\ (\underline{98.2}) + (\underline{250})\ (\underline{39.6}) + (\underline{250})\ (\underline{43.25}) + (\underline{300})\ (\underline{28.3})\right]/60$$

$$C_o = \underline{977.70} \text{ dollars}$$

Step 16. Total Loading Cost, C_ℓ

$C_\ell = (T_\ell c_\ell)/60 = \frac{(80)}{60}(150)$

$C_\ell =$ 200 dollars

Step 17. Productivity, PROD

PROD = 60 A_s/T_T = 60 (715) / (289.35)

PROD = 148.3 ac/hr or ha/hr

Step 18. Efficiency, EFF

EFF = 100 $(T_s + T_u)/T_T$ = 100 (98.2 + 28.3)/(289.35)

EFF = 43.72 %

Step 19. Total Cost, C_T

$C_T = C_o + C_\ell =$ (977.20) + (200)

$C_T =$ 1,177.20 dollars

Step 20. Total Operation Cost/Hour, R_t

$R_t = 60\ C_T/T_T$ = 60 (1,177.20 / (289.35)

$R_t =$ 244.11 $/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$R_a = C_T/A_s$ = (1,177.20) / (715)

$R_a =$ 1.65 $/ac or $/ha

Example No. 3

Assumptions

1. A single helicopter is used and the aerial spray layout is depicted in figure 4.

2. There are two areas to be sprayed. The areas are designated Area 1 and Area 2, respectively. The spray starting points are labeled S_1 and S_2. See the accompanying drawing of the target areas.

3. There are two helispots, designated HS 1 and HS 2.

4. The spray paths are as indicated in the figure.

5. A heavy dot with an arrow indicates the end of a spray cycle. The accompanying integer indicates the spray cycle.

6. The helicopter is to be ferried from its home base, a distance of 10 kilometers. Thus, d_a = 20 km.

7. The relevant data are as shown on the data sheet.

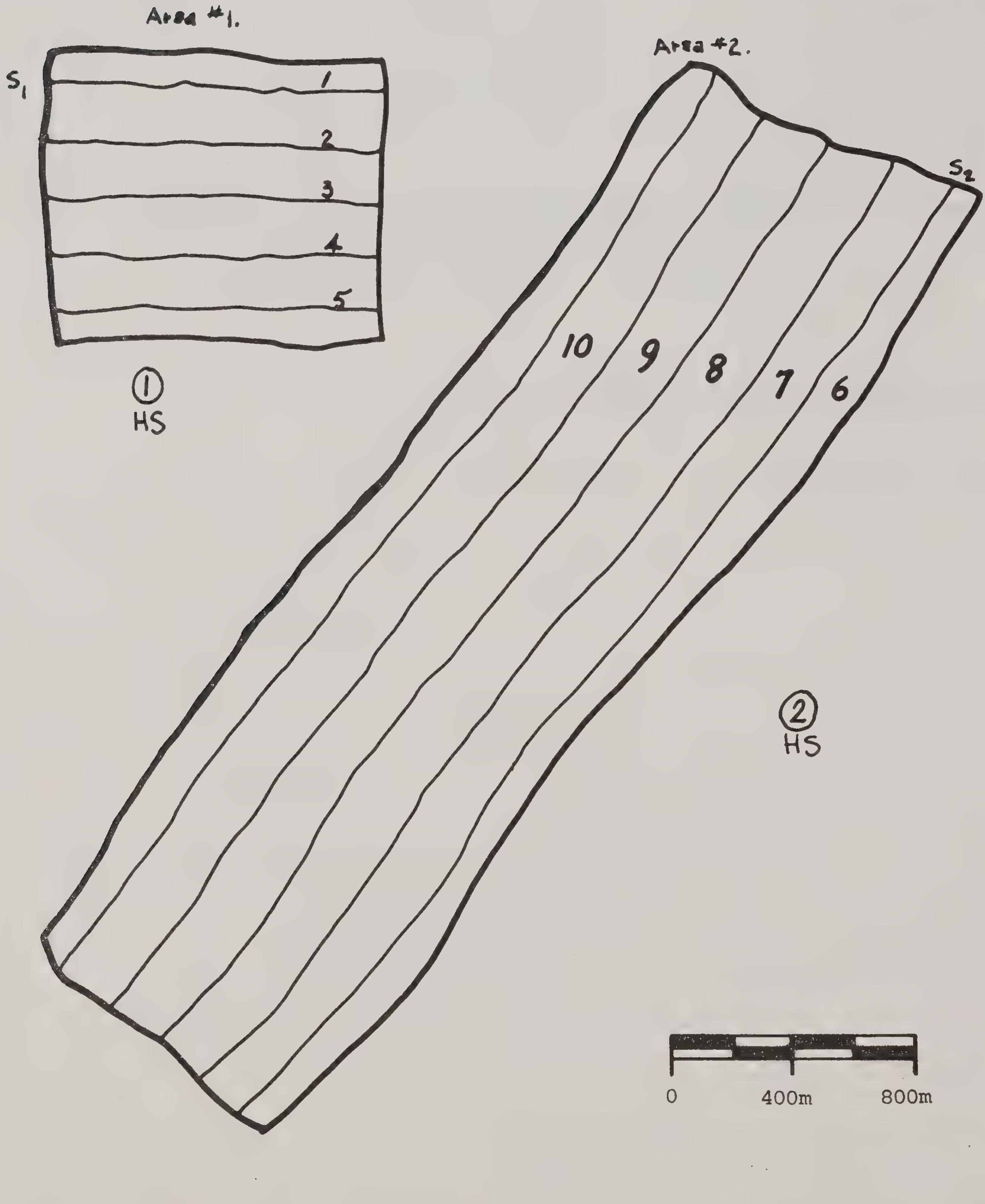

Figure 4.--Aerial spray layout for Example 3.

Example 3

Input Data Sheet

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	440 ha
Target Dim**	mi or km	L, W	
Application Rate	g/Ac or l/ha	a_r	6 l/ha
Tank Capacity	g or l	Q_f	1,200 l
Swath Width	ft or m	s_w	60 m
Spray Speed	mi/hr or km/hr	v_s	240 km/h
Ferry Speed	mi/hr or km/hr	v_f	250 km/h
Turning Time	sec	t_t	24
Aux. Ferry Dis.	mi or km	d_a	20 km
Touchup Const. of Prop.		k_u	0.2
Spraying Cost Rate	$/hr	c_s	300
Ferrying Cost Rate	$/hr	c_f	275
Turning Cost Rate	$/hr	c_t	290
Touchup Cost Rate	$/hr	c_u	300
Loading Cost Rate	$/hr	c_ℓ	150
Loading Time/Cycle	min	t_ℓ	25

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Worksheet

Some of the calculations are considerably simplified if a rectangular approximation to the target area is permitted. Separate calculation steps for these cases are given.

Step 1. Target Area, A_s

A_s = 440 Ac or ha

Rectangular shaped spray area

a. L and W in miles

$A_s = 640\ LW = 640\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ac

b. L and W in km

$A_s = 100\ LW = 100\ (\_\_\_\_)\ (\_\_\_\_) = \_\_\_\_$ ha

Step 4. Pesticide Flow Rate, f_r (g/min or l/min)

$f_r = c_r a_r v_s s_w$

$= (0.00167)\ (6)\ (240)\ (60)$

f_r = 144.3 g/min or l/min

where: $c_r = \frac{1}{495}$, if a_r in g/ac, v_s in mi/hr and s_w in ft or

$c_r = \frac{1}{600}$, if a_r in l/ha, v_s in km/hr and s_w in m.

Step 5. Spray Distance per Cycle, d_s (mi or km)

$$d_s = \frac{Q_f v_s}{60 f_r} = \frac{(1200)\ (240)}{60\,(144.3)}$$

d_s = 33.3 mi or km

Note: d_s in mi or km according to the units of Q_f, v_s, and f_r. These units must be compatible.

Step 6. Total Spray Distance, D_s (mi or km)

This calculation is made in accord with the discussion concerning step 6 of the procedures. The accompanying worksheet may be used as an aid. The sum called for at the bottom of the third column is the sum of the total lengths of the associated spray paths. If more than one worksheet is used, D_s is the total of the sums appearing at the bottom of each worksheet. The sum of the numbers appearing in the second column is the required number of turns for spraying (see item 9).

D_s = 73.14 mi or km

Rectangular shaped spray area

$$D_s = K\left(\frac{W}{s_w}\right) L = \frac{(\quad)}{} \; \frac{(\quad)}{(\quad)} \; \frac{(\quad)}{}$$

D_s = ______ mi or km

Where L is the length of the side of the rectangle paralleled by the spray path and W is the length of the remaining side, and where K = 5280 if dimensions in mi and ft or K = 1000 if dimensions in km and m.

Step 7. Number of Spray Cycles, N_c. (Round up)

$$N_c = \frac{D_s}{d_s} = \frac{(73.14)}{(33.3)}$$

N_c = 3

Worksheet (for Step 6)

(Not required if rectangular Approximation used.)

Spray Line No.	Spray Line Length ft or m	Number of Spray Paths Associated with the Spray Line	Total Length of Spray Paths Associated with the Spray Line ft or m
1	1,140	3	3,420
2	1,140	3	3.420
3	1,120	3	3,360
4	1,090	3	3,270
5	1,080	3	3,240
6	3,880	3	11,640
7	3,880	3	11,640
8	3,770	3	11,190
9	3,680	3	11,040
10	3,640	3	10,920
		Total (for item 9) N_s = 30	Sum (ft or m) D_s = 73,140
			Sum* (mi or km) D_s = 73.14

*Indicates divide D_s (ft or m) by 5280 or 1000 respectively.

Step 8. Data Sheet for Total Spray Cycle Ferry Distance, D_f (mi or km).
(The use of this sheet is optional.)

The spray cycle ferry distances, d_f, including the ferry distances within the cycle are obtained from the scaled layout and are to be entered in the table below.

Cycle Number n	From local base to starting point d_f (mi, or km)	From ending point to local base d_f (mi, or km)	Ferry distance within the cycle d_f (mi, or km)
1	1.1	0.6	2
2	0.6	2.0	
3	2.0	2.1	
Totals	3.7	4.8	2

D_f = Sum of the totals.

= 3.7 + 4.8 + 2

D_f = 10.5 mi or km.

Step 9. Total Number of Turns, N_t

For a nonrectangular shaped spray area, N_s is the sum appearing at the bottom of column 2 of the worksheet for item 6. If more than one such worksheet is required, N_s is the total of the sums (round up).

N_s = 30

$N_f = 2N_c = 2$ (3) = 6 , and N_a = 2

$N_t = N_s + N_f + N_a$ = (30) + (6) + (2)

N_t = 38

For a rectangular shaped spray area*

$N_s = K_t \frac{W}{s_w}$ = (____) $\frac{(\_\_\_\_)}{(\_\_\_\_)}$ = ______ (K_t = 5280 if dimensions are in ft and mi or K_t = 1000 if dimensions are in m and km)

$N_f = 2N_c = 2$ (____) = ____, and N_a = ________

$N_t = N_s + N_f + N_a$ = (____) + (____) + (____)

N_t = ________

Step 10a. Total Ferry Time, T_f (min)

$$T_f = 60 \frac{(D_f + d_a)}{v_f} = 60 \left(\frac{10.5 + 20}{(250)}\right)$$

T_f = 7.3 min

Step 10b. Total Spray Time, T_s (min)

$$T_s = 60 \frac{D_s}{v_s} = 60 \left(\frac{73.14}{240}\right)$$

T_s = 18.3 min

---

*In this calculation, W is the length of the side of the rectangle, which side is perpendicular to the direction of the spray path.

Step 10c. Total Turning Time, T_t (min)

$$T_t = \frac{N_t t_t}{60} = (\underline{38})\ (\underline{24})\ /60$$

$$T_t = \underline{15.2}\ \text{min}$$

Step 11. Total Touchup Time, T_u (min)

$$T_u = k_u\ (T_s + T_t) = (\underline{0.2})\ (\underline{18.3} + \underline{15.2})$$

$$T_u = \underline{6.7}\ \text{min}$$

Step 12. Total Loading Time, T_ℓ (min)

$$T_\ell = N_c\ t_\ell = (\underline{3})\ (\underline{25})$$

$$T_\ell = \underline{75}\ \text{min}$$

Step 13. Total Flying Time, T_o (min)

$$T_o = T_s + T_f + T_t + T_u = (\underline{18.3}) + (\underline{7.3}) + (\underline{15.2}) + (\underline{6.7})$$

$$T_o = \underline{47.5}\ \text{min}$$

Step 14. Total Operation Time, T_T (min)

$$T_T = T_o + T_\ell = (\underline{47.5}) + (\underline{75})$$

$$T_T = \underline{122.5}\ \text{min}$$

Step 15. Total Flying Costs, C_o.

$$C_o = (c_s T_s + c_f T_f + c_t T_t + c_u T_u)/60$$

$$= \left[(\underline{300})\ (\underline{18.3}) + (\underline{275})\ (\underline{7.3}) + (\underline{290})\ (\underline{15.2}) + (\underline{300})\ (\underline{6.7})\right]/60$$

$$C_o = \underline{231.9}\ \text{dollars}$$

Step 16. Total Loading Cost, C_ℓ

$C_\ell = (T_\ell c_\ell)/60 = \frac{(75)}{60}(150)$

$C_\ell =$ 187.5 dollars

Step 17. Productivity, PROD

PROD = 60 A_s/T_T = 60 (440) / (122.5)

PROD = 215.5 ac/hr or ha/hr

Step 18. Efficiency, EFF

EFF = 100 $(T_s + T_u)/T_T$ = 100 (18.3 + 6.7)/(122.5)

EFF = 20.4 %

Step 19. Total Cost, C_T

$C_T = C_o + C_\ell$ = (231.9) + (187.5)

C_T = 419.4 dollars

Step 20. Total Operation Cost/Hour, R_t

R_t = 60 C_T/T_T = 60 (419.4) / (122.5)

R_t = 205.4 \$/hr

Step 21. Total Operation Cost/ac or Cost/ha, R_a

$R_a = C_T/A_s$ = (419.4)/(440)

R_a = 0.95 \$/ac or \$/ha

A PLANNING AID EXAMPLE

By comparing the spray efficiency and the spray productivity corresponding to different sets of aircraft spray and flight characteristics, it is possible to select the optimum aircraft and spray characteristics for a specified aerial spray operation. In this way the procedure is an aid as a planning tool for the aerial spray designer.

The following is an example of how the procedure can be used to evaluate different aircraft for an aerial spray operation. Let the area to be sprayed, as well as the application rate, be that which is specified in example 1. Let the flight characteristics and operating costs of aircraft A be the same as those listed in example 1. The flight characteristics and operating costs of aircraft B are given in table 1. Aircraft C is identical with aircraft B except the former furnishes a 75-foot spray swath rather than a 90-foot spray swath.

Table 2 contains a summary of the relevant calculations obtained by applying the calculation procedure to each of the three aircraft

Table 1. -- Input Data Sheet (Aircraft B & C)

Variable	Units	Symbol	Magnitude
Target Area*	Ac or ha	A_s	
Target Dim**	mi or km	L, W	3 3/8 x 1 3/4 mi
Application Rate	g/Ac or l/ha	a_r	1.5 g/Ac
Tank Capacity	g or l	Q_f	400 g
Swath Width	ft or m	s_w	90 ft
Spray Speed	mi/hr or km/hr	v_s	120 MPH
Ferry Speed	mi/hr or km/hr	v_f	120 MPH
Turning Time	sec	t_t	36 sec
Aux. Ferry Dis.	mi or km	d_a	90 mi
Touchup Const. of Prop.		k_u	0.1
Spraying Cost Rate	$/hr	c_s	220 $/hr
Ferrying Cost Rate	$/hr	c_f	220 $/hr
Turning Cost Rate	$/hr	c_t	220 $/hr
Touchup Cost Rate	$/hr	c_u	220 $/hr
Loading Cost Rate	$/hr	c_ℓ	220 $/hr
Loading Time/Cycle	min	t_ℓ	20

*Required if target area not suitably approximated by a rectangle.

**Indicates required quantity if rectangular approximation to the spray area is used.

Table 2. -- Summary Calculations

	Aircraft A	Aircraft B	Aircraft C
Hourly Costs, $c_s=c_f=c_t=c_u=c_\ell$	200 \$/hr	220 \$/hr	220 \$/hr
Spray Speed v_s	90 mph	120 mph	120 mph
Ferry Speed v_f			
Swath Width, s_w	75 ft	90 ft	75 ft
Total Operation Time - T_t	830.8 min	654.7 min	770.6 min
Total Flying Costs - C_o	\$1719.33	\$1300.48	\$1505.53
Total Loading Costs - C_ℓ	\$1050.00	\$1100.00	\$1320.00
Productivity - PROD	273 Ac/hr	364.4 Ac/hr	294.3 Ac/hr
Efficiency - EFF	37.9%	17.4%	30.9%
Total Cost - C_T	\$2769.33	\$2400.18	\$2825.53
Cost/hr = R_t	\$200/hr	\$220/hr	\$220/hr
Cost/Ac - R_2	\$0.73/Ac	\$0.635/hr	\$0.75/Ac

An analysis of the results in table 2 shows that:

1. The smaller, slower aircraft has the greatest efficiency. This may be explained by noting that the touch up time for each aircraft is very small in comparison to the total spraying time. Thus, since the efficiency of each aircraft is the ratio of the sum of the touch up time and the spray time to the total operation time, the longer the spraying time, the greater the efficiency. A similar result is obtained when the efficiencies of aircrafts B and C are compared. However, the productivity, that is the number of acres sprayed per hour, is the greatest for the larger aircraft with the larger spray swath. In contrast, the smaller aircraft has the least productivity. Consequently, it seems that efficiency is a measure which can be misleading if it is not correctly interpreted.

2. Aircraft B is the most productive as well as having the lowest cost per acre.

3. A comparison of the cost per acre sprayed for aircraft A with aircraft B reveals that the smaller and slower aircraft is more cost effective, though not by very much. This is due to the fact that the swath widths for each aircraft are identical and the faster aircraft is the more expensive to operate.

4. The smallest total cost is obtained by using aircraft B while aircrafts A and C have about the same cost. This is due to the fact that, for the same swath width, the corresponding increase in speed and carrying capacity cannot offset the increase in operation cost of the larger and faster aircraft.

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